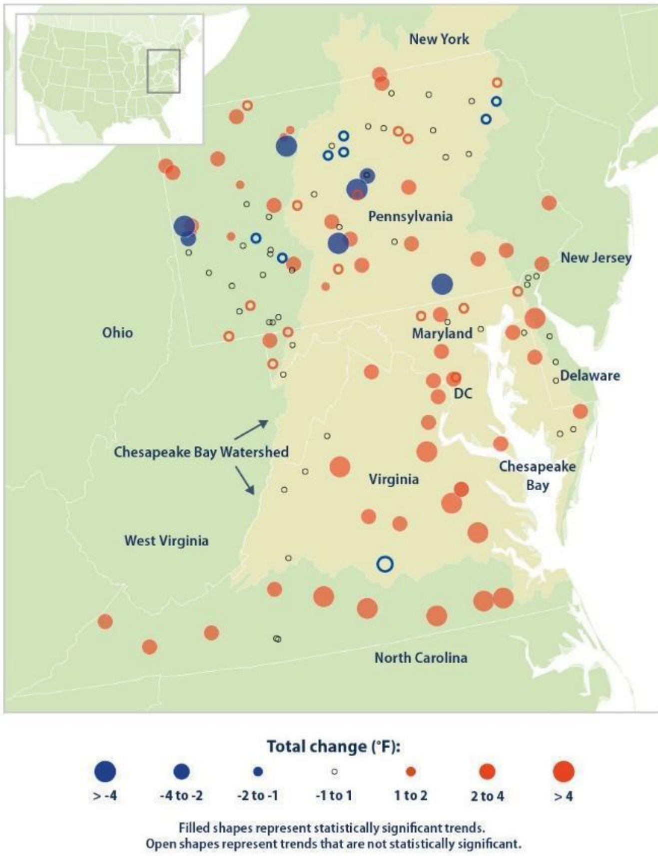
What We Know (and don't know) Now: Watershed Storyline



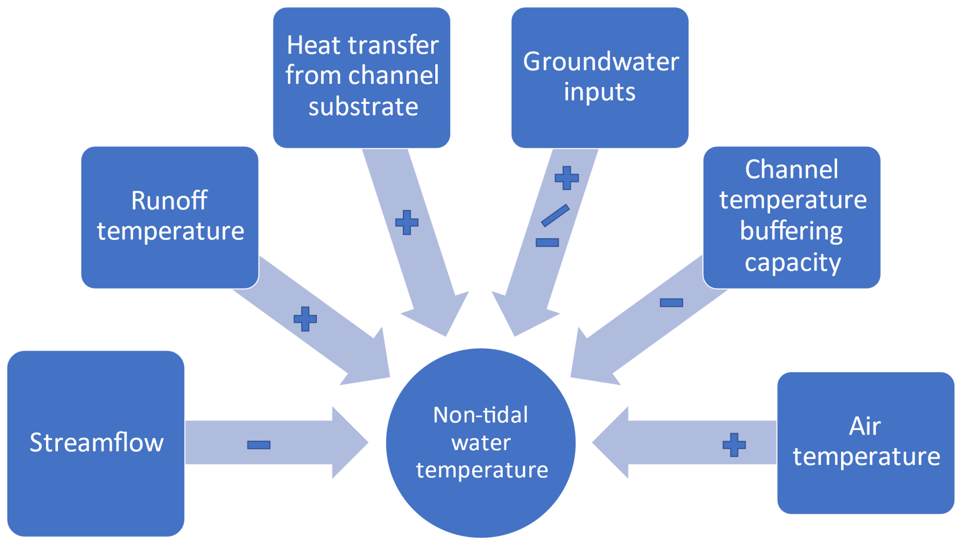
Water temperatures have been increasing in streams and rivers of the Chesapeake Bay watershed – even more than in the Bay's tidal waters. Furthermore, generally, water temperatures increased more than air temperatures from 1960 to 2010 (Rice and Jastram, 2015), demonstrating that in non-tidal waters, air temperature is not always the primary driver of water temperature. Air to water temperature ratios at sites show where land use or other factors are driving or buffering changes in water temperature.

Rising water temperatures have major implications for stream ecosystems, local communities, as well as land and water management. Impacts on vulnerable coldwater species, such as the eastern brook trout, are of particular concern.

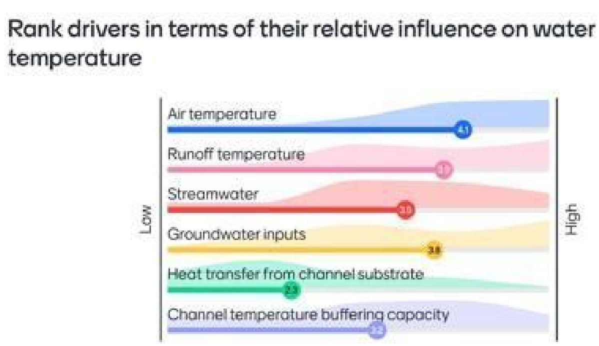
Drivers of Increasing Water Temperature

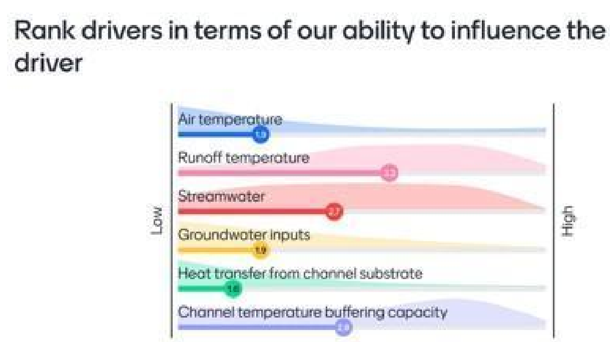
Increasing stream and river temperatures have been driven by rising air temperatures, but other drivers have a strong influence. The workshop team developed a conceptual model (below) summarizing the mechanistic drivers of non-tidal water temperature and their direction of influence. Negative arrows indicate drivers that can reduce water temperatures or provide a buffer against warming water temperatures. Positive arrows indicate drivers that can further exacerbate rising water temperatures. Many other interacting factors influence these broader drivers, and a more detailed conceptual model is provided in the BMP synthesis paper. Land use, for example, has a significant impact on streamflow and runoff temperature.

However, the relative importance of each driver will vary depending on the focal landscape and the spatial and temporal scale of interest. Certain drivers will have a stronger influence either in the short or the long term, and certain drivers will have a more localized influence on water temperatures (i.e., channel buffering capacity), while others may have a broader influence on water temperature across the landscape (i.e., upstream land use). Additional work is needed to connect these mechanistic drivers with specific management activities and land use decisions to better inform management.



During Day 1 of the workshop, participants were asked to rank the primary drivers in terms of their relative influence on water temperature and our ability to influence the driver. Most of the drivers ranked highly in terms of their influence on water temperature. Runoff temperature, stream flow and channel buffering capacity were also identified as drivers that we can influence through management. Other drivers, like groundwater inputs, may nonetheless be important to consider when identifying places that may be more resilient to climate change to targeting for conservation.

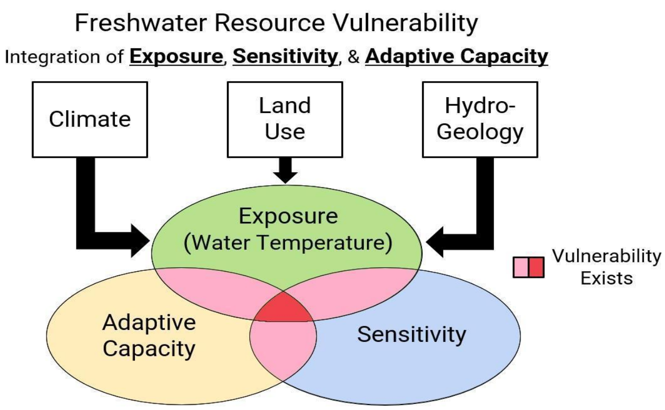




Drivers of rising water temperatures: Priority information needs

A key uncertainty is the degree to which various drivers and interactions between drivers influence water temperature in specific sub-watersheds. More localized information is needed to inform management. Greater high-frequency or continuous water temperature monitoring is needed to better understand the relative local influence of various drivers as well as water temperature trends (including seasonal effects). State water quality standards monitoring that focus on point source impacts may not be as useful for monitoring broader spatial and temporal trends. Additional monitoring is also needed at the air/water interface to identify hotspots where drivers are having a particularly large impact on water temperature as a way to target management. Finally, improved understanding of groundwater inputs is needed. Specific needs include better regional/sub-watershed models, more localized information about groundwater inputs, and a better understanding of how climate change could impact groundwater inputs.

Ecological Implications of Rising Water Temperatures



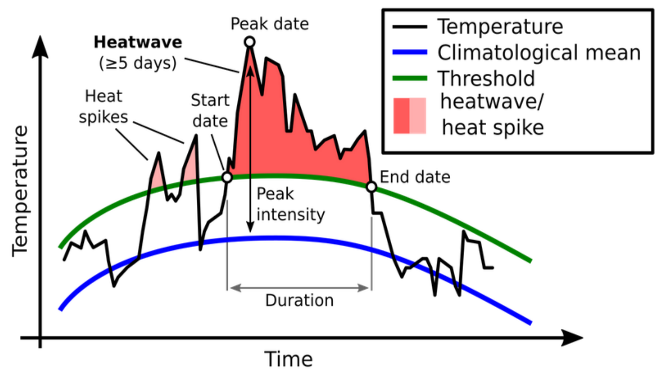
The workshop team developed a high-level conceptual model of freshwater resource vulnerability. This biophysical model does not include resource management considerations, such as the costs associated with protecting species or habitats. The model integrates a species or a habitat's vulnerability based on its **exposure** to rising water temperature, its **sensitivity**, as well as its **adaptive capacity**.

Warmer water temperatures will negatively impact aquatic habitats and threaten many ecologically and economically important species. It is expected that the strongest negative species-level impacts will be on coldwater species (e.g., trout, sculpin) due to their exposure and sensitivity to rising water temperature. However, watershed-wide, warm water aquatic species are most common. Although more tolerant to temperature increases, they are sensitive to extreme temperatures and to indirect effects of higher temperatures, such as lower dissolved oxygen concentration and competition with non-native species.

Workshop participants were asked to rank eight species in terms of their relative exposure and sensitivity to rising water temperature. Participants perceived a positive relationship between a species' perceived exposure to rising temperature and a species' sensitivity to rising temperature. Brook trout and checkered sculpin (coldwater species) were ranked the most exposed and sensitive to rising water temperature (*Note: most of the respondents to this poll with fish expertise work in cold water systems*).

The strongest negative impacts will likely be on relatively small, coldwater streams not driven by groundwater. These vulnerable systems are also where we find our most sensitive species and is why protecting native brook trout habitat and their contributing watersheds are an urgent priority. Spatial characteristics, including cross-sectional features of the stream channel, aquatic connectivity, and landscape features and whether there are accessible thermal refugia during extreme heat events can also influence exposure to rising water temperatures. Larger waterways with low forested watershed cover, riparian cover, and heated urban runoff are particularly vulnerable to warming.

The ecological impacts of rising water temperature are influenced by the specific ways in which temperature is warming. Shifts in seasonality (e.g., warmer winters, shift in season length) may impact spawning timing or migration which could influence exposure to rising water temperature. Pulsed extreme warm water events (i.e., heatwaves) have a disproportionate impact on the environment relative to long-term changes in mean water temperature. Aspects of aquatic heatwaves that are likely to affect vulnerable species include heatwave frequency, duration, intensity, and onset rate.



Rising water temperatures may increase the occurrence or co-occurrence of known stressors that negatively impact aquatic species and habitats. Water temperature is a catalyst for biochemical reactions that negatively impact habitat quality at high water temperatures. Some known stressors that occur as temperature increases include:

- Low dissolved oxygen: gas solubility decreases with increasing water temperature (warm water holds less oxygen than cooler water).
- Invasive species: warmwater species have a longer invasion window open.
- Algal blooms: cyanobacteria known to perform well with elevated water temperatures.
- Bacterial/viral outbreaks: warmwater increases physiological stress making it harder for species to fight off infection.
- Distribution & toxicity of other pollutants (e.g., heavy metals, pesticides, ammonia, etc): Rising water temperature mobilizes and increases the toxicity of other pollutants.

Increasing water temperatures will likely alter ecosystem structure and function: Ecosystems may move from diatom dominated to green-algae or cyanobacteria dominated. This alteration would represent a shift towards less nutritious food sources. Increasing water temperature will further isolate coldwater populations while expanding the range of warmwater and non-native species. As novel communities interact there will be shifts in predator/prey interactions that are likely to alter energy and nutrient flow.

Ecological implications of rising water temperatures: Priority information needs

More research is needed on the impacts of elevated temperature to non-trout species, including lower parts of the food web such as algae, biofilms, zooplankton, macroinvertebrates. More research is also needed on the impacts of elevated temperature on species life stages, predator prey interactions, and how these interact with multiple stressors. Additional high-frequency (sub-daily) monitoring is needed to understand which places are most exposed and sensitive to pulsed heating events such as heatwaves. Furthermore, there is a need to integrate water temperature datasets across federal, state, and academic institutions as well as those required to monitor as part of permitting.

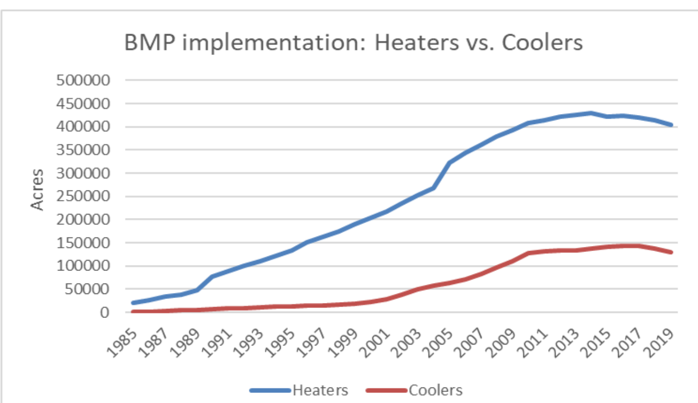
Management Implications

Multiple policies and practices could be considered to address the drivers of rising water temperature and ecological implications. These include policies that promote the protection and maintenance of natural lands that provide cooling benefits, including forests, wetlands and healthy watersheds and Best Management Practices (BMPs) included in Watershed Implementation Plans (WIPs) or in habitat restoration strategies.

Conserving existing healthy watersheds can help promote resiliency to rising water temperatures. Key factors of healthy watersheds that may moderate rising temperatures include:

- Land use/land cover: % forest cover (catchment and riparian), % natural land cover
- Hydrology/flow alteration, including infiltration rates of land use/land cover types
- Underlying geology/groundwater interaction

Promoting practices that maintain or increase forest and natural land cover types, reduce flow alteration of streams, and utilize our understanding of underlying geology and groundwater recharge can increase resiliency to rising water temperatures.



Some BMPs have the potential to mitigate rising water temperatures, but watershed-wide, there has been substantially greater implementation of "heater" BMPs as compared with "cooler" BMPs. BMPs can influence water temperature by impacting multiple drivers of water temperature identified in the conceptual model. The workshop team conducted a synthesis effort evaluating the temperature impacts of Bay Program BMPs and grouped BMPs based on the strength and direction of their impact on water temperature. **"Heaters"** include stormwater retention ponds, floating treatment wetlands and vegetated open channels. **"Coolers"** include riparian forest buffers, upstream tree planting, urban stormwater infiltration, and wetlands restoration, enhancement and rehabilitation. Many BMPs were classified as either "uncertain" or "thermally neutral". In many years, there has been approximately 3x as much implementation of heaters as coolers, suggesting that some of the practices we are implementing to improve water quality may be having adverse, unintended consequences for water temperature.

Management Recommendations

Coldwater Fisheries and Habitats Recommendation

Chesapeake Bay Program (CBP) partners need to accelerate conservation to protect coldwater streams supporting healthy aquatic life, especially native brook trout, which are extremely sensitive to rising water temperatures.

Rationale: Even though the CBP partnership is committed to brook trout stream protection and restoration, suitable brook trout habitat is still diminishing, due to development and especially loss of riparian forest. Stream warming increases the urgency to identify the best habitat for land conservation and other restoration actions and there are excellent mapping tools for habitat identification. Cold groundwater input increases a stream's capacity for supporting coldwater fisheries, but more data is needed on local groundwater inputs to identify streams that may be particularly vulnerable or resilient to warming surface water temperatures.

Although these coldwater habitats are sometimes found in already healthy watersheds, there can also be opportunities to use restoration and BMPs to minimize stream warming in these important habitats. For example, where there are farms in these watersheds, partners should prioritize working with agricultural landowners to minimize the potentially adverse impacts of agricultural practices to stream temperatures. Likewise, in lands degraded by former minelands or other extractive land uses, upstream reforestation activities can be used to increase infiltration, reducing the extent to which heated runoff is entering waterways.

Implementation Actions:

1. Prioritize protecting forested watersheds and riparian buffers with quality brook trout habitat by maintaining and enhancing current forest cover.
2. Promote good agricultural stewardship, including better use of cooling BMPs, to minimize the impacts of agricultural land use in watersheds with high quality brook trout habitat
3. In priority coldwater habitat areas for conservation and restoration:
    a. Develop stronger engagement with private landowners, including working with ag agencies to promote cooling practices, and improving conservation easement programs and incentives.
    b. Work with local governments to improve land use planning in high quality habitat

areas and to better utilize new and existing program for coldwater fisheries

4. Implement habitat restoration in degraded landscapes, including the reforestation of abandoned minelands and the restoration of degraded streams to improve connectivity and expand available habitat, while minimizing the loss of mature riparian trees
5. Develop a strategy that pulls federal, state (e.g., Dept. of Transportation), private, NGO, and landowner resources together for coldwater conservation partnerships.

Science Needs to Support Implementation: Increased continuous, high-frequency surface water temperature monitoring in headwater (i.e., coldwater) streams will help to identify and prioritize waterways for restoration and conservation. Likewise, implementing sediment/benthic temperature monitoring along with groundwater mapping will help determine which waterways are most resilient to warming and provide the greatest opportunity for brook trout persistence in the future. Lastly, longer-term temperature and brook trout monitoring will provide richer insight into factors contributing to restoration and watershed conservation success.

Rural Waters and Habitats Recommendation

In rural areas, CBP partners should work to strategically restore forests and aquatic habitats while promoting good agricultural stewardship practices that can reduce the amount of heated runoff being generated by farms.

Rationale: Rural landscapes are highly variable, providing important lands and waters for agricultural production, habitat and communities. Given this variability, an equal level of effort won't always lead to equal outcomes for stream temperature in different landscapes. A strategic approach to restoring forests and aquatic habitats will ensure that resources are spent in the places and on the practices that will have the greatest benefits for cooling waterways. Riparian forest buffers are essential for cooling waterways; however, riparian buffers will only get us so far, and other upstream practices are needed to minimize stream warming.

On agricultural lands, the Bay Program has generally focused on practices that generate nutrient and sediment reductions. Unfortunately, some best management practices that are very effective at reducing nutrients and sediments, such as farm ponds, can contribute to stream warming. Strategic whole-farm planning could help ensure that cooling practices are utilized to minimize trade-offs between water quality and water temperature.

At the same time, within streams, the Bay Program should work to strategically restore aquatic habitats to minimize the impacts of warming temperatures on aquatic biota and ecosystems. For example, there are opportunities to improve aquatic connectivity between suitable habitat patches that could improve access to thermal refugia during peak summer water temperatures.

Implementation Actions:

1. Improve forest cover throughout the landscape and ensure rivers and streams are well buffered.
2. Use the improved Bay watershed mapping capability to prioritize specific headwater stream reaches where riparian buffer plantings can exert the greatest cooling impact in rural watersheds.
3. Use aquatic habitat restoration to improve connectivity between suitable habitat patches and improve access to thermal refugia.
4. Improve technical assistance and programs available to private landowners for tree planting and conservation.
5. Work with local government planning departments to modify codes and laws where appropriate to require conservation BMPs and cooling practices.

Science Needs to Support Implementation: In rural areas, there is a need for targeted research in small agricultural watersheds to measure temperature impacts of agricultural land and water management practices, including infiltration practices. There are also opportunities to further investigate the efficacy of other cooling mitigation strategies, including dam/pond removal, floodplain restoration, beaver analogue projects, and improved roadside ditch management. Finally, CBP partners could use the new high-resolution land use data to determine the maximum rural stream mileage available for forestation and develop models to determine whether the installation of future stream "cooler" and "shader" practices will mitigate watershed warming factors.

Urban Waters and Habitats Recommendation

In urban areas, CBP partners should improve the use of BMPs to reduce the amount of heated runoff entering waterways, especially in under-served urban areas which historically suffer the worst heating and human health outcomes.

Rationale: Urban rivers and streams tend to be particularly vulnerable to the effects of stream warming, as the prevalence of impervious surfaces increases the volume and temperature of runoff entering waterways. Some of the best management practices (BMPs) used to improve water quality in urban areas, such as stormwater detention ponds, can also warm surface runoff. To minimize these trade-offs between water quality and water temperature, Bay Program partners should identify opportunities to further incentivize the use of BMPs that provide cooling benefits over the use of BMPs that further heat waterways. "Cooling" BMPs include certain urban practices, including bioretention, porous pavement, and infiltration practices without underdrains, as well as tree planting, lawn conversion and urban forest buffers. These practices also provide myriad other benefits to urban communities, including cooling air temperatures and improving air quality. Where possible, Bay Program partners should use existing environmental justice and equity mapping tools to identify locations where implementing these practices could be particularly beneficial to historically under-served populations.

There is tremendous variability across developed areas in the Bay watershed, ranging from small townships to large metropolitan areas with varying hydrology, soil conditions, and proportions or types of impervious and pervious cover. For urban areas adjacent to wider rivers and waterways, it may be more difficult to directly cool streams. In these places, partners should identify opportunities to create thermal refugia or improve access to thermal refugia through in-stream habitat restoration work. These thermal refugia may be particularly important for aquatic biota in urban streams, where warming water temperatures may further compound the adverse impacts of degraded water quality. However, it is important to minimize the extent to which stream restoration disturbs existing riparian canopy coverage to maintain the important cooling benefits provided by riparian trees.

Additionally, stormwater runoff for some areas will be captured by combined stormwater and sewage systems, while most areas have separate storm sewers and sanitary sewage lines. The cooling or heating impact of combined versus separate sanitary sewer systems was not explored in depth but is worth further exploration. In areas with combined sewer systems, there are often initiatives to promote green stormwater infrastructure that can lower the volume and temperature of runoff that enters the system.

Another important factor that arose in workshop discussions was the intersection of human health impacts and rising water temperatures. Urbanized areas often have areas with legacies of toxic pollution from industrial or other sources, and these legacies can have lasting impacts on local soils or waterways depending on the pollutant and its ecotoxicity pathways. Bacteria and harmful algal blooms are also relevant human health concerns for numerous waterways. Water temperature can influence these pollutants, how they move through the ecosystem, and how they ultimately impact aquatic biota and human health. These human health concerns are doubly important when considering the disproportionate historical and continued impact of pollution on under-served communities of color.

Implementation Actions:

1. Decrease the amount of lawns in cities, using lawn conversion programs to increase urban tree cover.
2. Encourage the retention and expansion of urban tree cover (both in the riparian zone and upstream), especially in under-served urban areas which historically suffer the worst heating and human health outcomes.

3. Use aquatic habitat restoration to improve connectivity between suitable habitat patches and improve access to thermal refugia.
4. Emphasize the multiple co-benefits of cooler BMPs in the urban environment (beyond rising water temperatures and nutrient reductions) to better communicate about these practices with residents and local governments and to access additional sources of funding.

Science Needs to Support Implementation: For urban areas, the most significant science needs are to better understand how rising water temperatures interface with social science or public health issues, especially among under-served residents. Examples include evaluating the impacts of heated runoff and pollution concerns stemming from direct or indirect effects of elevated water temperature. An emphasis on improved understanding of locally relevant co-benefits for BMPs and restoration projects is also a priority science need.

State Temperature Water Quality Standards Recommendation

As Clean Water Act water quality standards (WQS) play a vital role in focusing federal, state, local and private actions to protect water quality and aquatic life, the states and EPA should review and modernize the components of current WQS systems that would strengthen their capability to address climate-related rising water temperatures and drive area-targeted protection and restoration strategies.

Rationale: All CBP jurisdictions have a "water temperature policy" in their temperature WQS, but it needs to be updated to deal with climate-related water warming. For decades, the standards (temperature criteria, monitoring schemes) have protected aquatic life and other water uses from heated discharges (e.g. power plants). Maryland officials showed workshop participants how they want to use temperature WQS to drive better protection of trout streams from impairments caused by climate and exacerbating land use impacts. The state added a forest buffer (shading) provision to its temperature criteria and is working on TMDL options. Workshop participants noted expert advice on temperature criteria – limits to protect aquatic life from heat discharges ("dots on the landscape") may not be protective for climate-related heating. Current monitoring regimes to detect impacts of discrete point sources need to be re-designed for climate-related heating. Participants had ideas for how to get started on the WQS modernization process. Just as the Bay WQS focused restoration action through the Bay TMDL and state WIPs, states and EPA can work together to update the WQS mechanisms related to temperature, taking advantage of a large body of temperature-related fisheries research and advice from experts throughout the US.

Implementation Actions:

1. Convene EPA and jurisdiction WQS practitioners to explore how to make Chesapeake Bay watershed WQS effective to combat rising water temperatures. Evaluate: accuracy of aquatic use zones (e.g. coldwater, coolwater, warmwater fisheries); refinement of temperature criteria (e.g. to protect growth and reproduction) for fisheries and corresponding biological criteria; monitoring/analysis methods and strategies adapted to climate-related temperature changes, taking into account land use influences and groundwater inputs. Evaluate TMDL options to spur restoration of temperature-impaired water uses. Can anti-degradation policies be leveraged to increase protection of current high quality waters, especially healthy native trout streams? Aim to complete this evaluation in 12 months, building in advice from experiences elsewhere in the U.S.
2. "Modernize" these Clean Water Act tools to improve jurisdictions' capability to protect indigenous populations of coldwater, coolwater and warmwater aquatic life from climate-related water temperature increases. The timing for making regulatory changes could be based on the established WQS triennial review process.
3. Interstate cooperation through CBP could increase effectiveness through information-sharing, problem solving and monitoring-modeling support.
4. Stronger anti-degradation measures could improve protection of temperature-threatened high-quality waters, e.g. native trout streams**.**

Science Needs to Support Implementation: As demonstrated by the ORSANCO compilation of temperature criteria (2005), there is a considerable body of research information on temperature effects on fisheries, and available information might support adoption of protective temperature criteria; however, information is more limited on growth/reproduction than lethality. Maryland's examples show the types of analysis and modeling associated with identifying those coldwater stream areas that are most amenable to conservation and restoration actions. Any action strategies will require site-specific information e.g. on species, benthic community, channel conditions, groundwater inputs. The highest priority is needed on devising cost-effective monitoring methods and strategies.

Best Management Practices (BMP) Recommendation

CBP partners should work to minimize the extent to which water quality BMPs are further heating waterways and strategically use cooling BMPs to counteract the warming effects of climate change and land use where possible.

Rationale: Certain water quality BMPs are known to warm surface water temperature, including wet ponds, detention ponds, farm ponds and CAFO lagoons. While these practices may be very effective and necessary to achieve the needed nutrient and sediment reductions, they may be having unintended consequences for water temperatures and stream ecosystems. There are other BMPs that can either directly cool waterways (i.e. riparian forest buffers) or can help minimize further stream warming (i.e. infiltration and bioretention practices).

However, over time, the use of heating BMPs has grown relative to cooling BMPs in the Chesapeake Bay Watershed, suggesting a need for renewed focus on incorporating temperature considerations into BMP selection and design. This focus is especially important near important coldwater habitat areas where species are particularly vulnerable to any further increases in stream warming. However, promoting cooling BMPs over heating BMPs throughout the watershed could be beneficial watershed-wide to minimize the heating effects of impervious land uses.

Implementation Actions:

1. Work with local governments to avoid using "heater" BMPs near brook trout streams and identify opportunities to incentivize stacking multiple stormwater “cooler” BMPs over “heater” BMPs.
2. For practices with the potential to exacerbate stream warming, develop specific design recommendations and criteria to minimize warming impacts. Relevant regulatory and stormwater permitting agencies should collaborate to review existing design criteria for new stormwater and restoration practices installed in cold and cool-water watersheds to avoid further stream warming.
3. For cooling practices whose efficacy is likely to be impacted by climate change, provide design recommendations to ensure these practices will remain resilient to likely future climate scenarios. This could include updating forestry BMP plant lists to make sure the species being planted are appropriate for the future hardiness zones in our warming watershed or encouraging diversity in plant selection to hedge against potential losses to invasive pests and plants.
4. Where heating BMPs are needed to effectively address water quality concerns (no suitable cooling BMP alternatives are available), take a whole farm, whole property or whole landscape approach to ensure that enough cooling BMPs are implemented to offset any warming attributable to heating BMPs.

Science Needs to Support Implementation: While we have a good understanding of the temperature effects of certain BMPs, there are many BMPs where we do not currently have a good understanding of temperature effects (for example, stream restoration, agricultural BMPs and wetlands BMPs). There is a need for a more robust assessment of which are heaters/coolers. This could involve using a systematic expert elicitation process to better identify the BMPs likely to influence water temperature as well as the direction and magnitude of the temperature impact. Targeted research efforts should also further evaluate how various landscape characteristics; including groundwater inputs, underlying geology and land cover; mediate the temperature effects of BMPs and the scale at which various BMPs need to be implemented to have a measurable impact on water temperature.

Research, Monitoring, and Modeling Needs and Recommendations

There were numerous science needs and recommendations generated during the workshops to better understand rising temperatures in the watershed. They have been grouped under three topics: research, monitoring and modeling, each having an overarching recommendation with supporting needs and actions. The topics are interrelated and a coordinated and intensive effort will be needed by the CBP partners to carry out the actions needed to address the recommendations.

Research Recommendation

The CBP should enhance and facilitate partnership efforts to collect data and develop tools needed to fill critical knowledge gaps, improve understanding of the impacts of rising temperatures on aquatic ecosystems, and inform management decisions.

Rationale: The workshop participants agreed that there are critical knowledge gaps and science needs limiting our understanding of the ecological impacts of rising water temperatures, linkages between causes and effects, interactions with other stressors, and how best to mitigate detrimental impacts. Coldwater fisheries are at high risk for habitat degradation and loss given their specific temperature thresholds; however, groundwater inputs were recognized as an important component that can mitigate temperature increases and provide thermal refugia. Information on coldwater species other than brook trout is quite limited. Given the many variables affecting the location and impact of groundwater inputs to streams (Snyder et al. 2015; Johnson et al. 2017; Briggs et al. 2018), additional research is needed to assist CBP and relevant stakeholders in identifying streams with groundwater inputs and providing the data necessary to improve existing models and develop new models (see Modeling recommendations). While not as vulnerable as coldwater fisheries to rising temperatures, warmwater fish species are more widespread throughout the watershed and there is little information on both direct and indirect effects of higher temperatures.

Science Needs:

1. Conduct climate vulnerability assessments to better understand both the exposure and sensitivity of species/habitats to rising temperatures, including indirect effects (e.g., invasive species), to better understand overall vulnerability. The assessments would consider various forecasts of land use, climate, and hydrogeology in estimating

exposure. The results would be useful in understanding the implications of restoration and protection plans and in the targeting of resources. Federal agencies could concentrate on regional assessments, while state agencies and universities could conduct more local assessments.

2. Collect additional data on the extent of deep and shallow groundwater to improve temperature-based estimates of climate refugia locations at finer spatial scales.
3. Determine how interactions between climate change and land use will affect brook trout and mussel populations including cumulative impacts.
4. Identify genetic metrics necessary to determine brook trout and mussel population resiliency to rising temperatures including adaptive variation to higher temperatures.
5. Conduct targeted research in smaller watersheds to improve understanding of temperature impacts of land use and water management practice and efficacy of BMPs to mitigate temperature-related impacts.
6. Use an integrative approach combining information on flows, stream power, connectivity, and adaptive capacity to provide a more comprehensive approach for identifying climate refugia.

Monitoring Recommendation

CBP partners could increase monitoring of water temperature in smaller streams, and further analyze existing data from larger streams and rivers, to improve understanding of the effectiveness of restoration and conservation of stream communities and fisheries in the face of land-use and climate change.

Rationale:

A wide array of monitoring needs identified during the workshop have been grouped into several topics:

1. Use stream temperature monitoring to assess if water temperatures are being sustained, or ecological thresholds exceeded, for sensitive populations of fish and stream communities. High-frequency (sub-daily) monitoring is needed to understand which places are most exposed and sensitive to pulsed heating events such as heatwaves. Additional monitoring is also needed to support state water quality temperature standards.
2. Document effects of different stressors on local stream temperatures. Higher-frequency or continuous water temperature monitoring is needed to better understand the relative local influence of various drivers as well as water temperature trends (including seasonal effects). Additionally, a need was identified for monitoring to quantify the relationship between rising temperatures and other constituents, including bacteria in urban areas.
3. Improve and increase monitoring data to better target locations for restoration and conservation activities in the three primary landscapes (coldwater, rural and urban). Monitoring data are insufficient for assessing temperatures in streams draining all

landscape areas. Smaller streams generally lack consistent monitoring for temperature and new temperature monitoring is needed in smaller streams important for coldwater fisheries. Additional monitoring is also needed at the air/water interface to identify hotspots where drivers are having a particularly large impact on water temperature to target management.

4. Assess the effects of selected management actions on stream temperature. The effects of selected BMPS on stream temperature is lacking and monitoring is needed to document these changes.

Science Needs:

1. Use existing monitoring data to assess changes, influencing factors, and important ecological thresholds of temperatures in rivers and streams. Status, trends, and correlations with land use types should be investigated. The existing data should also be explored for considering temperature standards for coldwater fisheries by the jurisdictions, similar to the effort by the Maryland Department of the Environment. An inventory of data collected by multiple agencies has been compiled by the USGS, and they could work with other partners on further analysis.
2. Establish a monitoring network in smaller streams and landscape settings important for biological communities and coldwater fisheries. The STAR could work with the CRWG to design and implement a monitoring network to assess factors affecting stream temperatures in three landscape areas: coldwater, rural, and urban. One opportunity would be to expand the USEPA Regional Monitoring Networks (RMN) to detect changing baselines in freshwater wadeable streams
3. Use monitoring and landscape information to help target locations for restoration and protection of areas from rising stream temperatures. Information from the healthy watersheds assessment could be coupled with remote sensing to detect groundwater discharge areas important for sustaining coldwater streams. Partners could include the HW GIT, USGS, and NASA.
4. Understand temperature and biological response to BMPs. Take advantage of on-going studies of BMP effectiveness to assess changes to stream temperature. This could be done by academic institutions and other partners conducting small watershed studies.

Watershed Modeling Recommendation

The CBP partnership should develop new modeling tools and expand the use of CAST and the Chesapeake Healthy Watershed Assessment (CHWA) to better inform the management of watershed fisheries and ecosystems.

Rationale: Current modeling tools used by the CBP partnership are not sufficient to meet the needs of freshwater fisheries managers. The most widely used CBP tools such as CAST and the CHWA are built to inform managers on nutrients and sediment, and general watershed health, respectively, at the large scale. They do not provide the types of information nor are they at an appropriate scale needed by fisheries managers making habitat protection and stocking decisions. New tools at the fine scale should be developed in selected areas for local management. New functionality should be added to existing tools to indicate how larger-scale land use and land management decisions would affect habitat.

Science Needs:

1. Develop fine-scale, process-based local models in selected areas that better simulate the influence of land use and groundwater on local steam temperatures. The model results would be useful to fishery managers in identifying areas that are in danger of exceeding temperature thresholds important for cold water species. Improved groundwater simulation will be crucial. USGS and other CBP partners may be able to identify resources to pursue development of fine-scale models.
2. The Healthy Watersheds Goal Implementation Team should better integrate the Chesapeake Healthy Watersheds Assessment (CHWA) with regional management models and with local habitat models. Local models may benefit from vulnerability indicators in the CHWA such as projected future development, wildfire risk, and climate change metrics. Findings from local habitat models can be used to improve the understanding of the linkage between vulnerability and habitat indicators in the CHWA. Regional models can share common data sets with the CHWA and can provide it with predictions such as stream temperature effects of climate change. The CHWA should be expanded to include stream temperature as a metric.
3. The CBPO's CAST team should develop scenario outputs related to temperature, fisheries, and biota effects to inform managers on the aggregate effects of their land use and land management decisions related to the Chesapeake TMDL. This will require the USGS and academic partners to adapt habitat models to be responsive to inputs or outputs available in CAST.