Climate Change Considerations When Prioritizing, Developing and Implementing Total Maximum Daily Loads

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Introduction

The U.S. Environmental Protection Agency's mission to protect human health and the environment continues to face unprecedented challenges due to climate change. To address these challenges, the EPA's *FY 2022-FY 2026 Strategic Plan*[1] includes a new goal focused exclusively on tackling the climate crisis, and one of the objectives is to accelerate resilience and adaptation to climate change impacts.[2] The EPA's 2021 *Climate Adaptation Action Plan*[3] and the EPA Office of Water's 2022 *Climate Adaptation Implementation Plan*[4] identify multiple ways that climate change can impact water quality, which can be interrelated and spatially or temporally variable. The U.S. Global Change Research Program's *Fifth National Climate Assessment* reports that "intensifying rainfall and floods, deepening droughts, and shifting weather patterns across the globe, [are] causing profound effects on terrestrial freshwater supplies and quality."[5] Depending on location and temporal variation, climate-related effects on water quality may include:

- Increased runoff contributing more sediment, nutrients and other pollutants to waterbodies affecting multiple uses.
- Lower streamflows leading to increased instream temperatures and fine sediment deposition which can affect cold water fisheries.
- Elevated temperatures impacting aquatic life, evapotranspiration rates and associated effects; releasing excess nutrients; promoting increased growth of algae and microbes; and influencing the bioavailability, mobility and transformation of certain pollutants, which affects the toxicity[6] of the pollutants to organisms.
- Reduced dissolved oxygen levels, caused by increased temperatures, increasing the prevalence of pathogens and water-related illnesses and causing fish kills both directly and through impacts from harmful algal blooms fed by increases in internal phosphorus loading.
- More frequent wildfires leading to impacts such as excess erosion and an increase in sediment and nutrient loading due to soil destabilization.[7]
- Rising sea levels amplifying erosion impacts and saltwater intrusion in coastal ecosystems.
- Rising concentrations of carbon dioxide in the atmosphere contributing to ocean acidification, which is also aggravated by rising temperatures due to climate change.[8]

For additional details and regional assessments of potential climate change effects on water quality, see the Fifth National Climate Assessment.[9]

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[1] U.S. EPA, FY 2022-2026 Strategic Plan, March 2022.
[2] U.S. EPA, FY 2022-2026 Strategic Plan Goal 1, Objective 1.2.
[3] U.S. EPA, Climate Adaptation Action Plan, Oct. 2021.
[4] U.S. EPA, Office of Water, Climate Adaptation Implementation Plan: Advancing Climate Change Adaptation and Resilience Through EPA's Water Programs. EPA-800-R-22-001, Sept. 2022.
[5] U.S. Global Change Research Program, Fifth National Climate Assessment, 2023.
[6] *See, e.g.*, Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater (2013).
[7] *See, e.g.,* Bladon, K., M. Emelkos, S. Uldis, and M. Stone (2014). "Wildfire and the Future of the Water Supply." Environmental Science and Technology, pp. 8936–8943.
[8] U.S. EPA, Integrated Reporting and Listing Decisions Related to Ocean Acidification Memo, Nov. 2010. Contributing citations in document: (NRC 20 IO; Ridgwell and Schmidt 2010; U.S. EPA 2009b, 2010c; NOAA 2008; Hoegh-Guldberg et al. 2007).
[9] U.S. Global Change Research Program, Fifth National Climate Assessment, 2023.

As the EPA's Office of Water marked the 50th Anniversary of the *Clean Water Act* in 2022, the EPA recognized both the progress made and the additional efforts needed to ensure that every community in the United States has access to clean and safe water. Achieving the CWA's objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters"[10] is more challenging due to climate change, as changing conditions can lead to more waterbody impairments, even when pollutant loadings remain stable.

Under Section 303(d) of the CWA and the EPA's implementing regulations, states, territories and authorized Tribes[11] are required to develop lists of water quality limited segments.[12] The statute and the EPA's regulations require that for the waters identified on the Section 303(d) list, each state, territory and authorized Tribe shall establish total maximum daily loads, according to a priority ranking.[13] Under the statute and the EPA's regulations, a TMDL shall be established at levels necessary to attain and maintain the applicable water quality standards with seasonal variations and a margin of safety, or MOS.[14] Climate change impacts, such as those described above, can directly and indirectly affect water quality pollutants and attainment of water quality standards in addition to introducing additional uncertainty to various elements of the TMDL planning, development and implementation processes. TMDL developers should, as relevant and appropriate, provide a reasoned explanation of how climate change is considered and addressed during the TMDL process.

This paper identifies a non-exhaustive selection of potential approaches for incorporating climate change considerations into TMDL prioritization, development and implementation that can be used individually or in combination, depending on each TMDL's circumstances (Figure 1). While this paper cites statutes and regulations that contain legally binding requirements, this paper does not impose any new requirements and does not constitute a prescriptive checklist for consideration of climate change.

Additionally, this paper references non-EPA websites. These external links provide additional information that may be useful or interesting and are being provided consistent with the intended purpose of this document. However, the EPA cannot attest to the accuracy of information provided by these links. Providing links to non-EPA websites does not constitute an endorsement by the EPA or any of its employees of the sponsors of the sites or the information or products presented on the sites.

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[10] CWA Section 101(a).

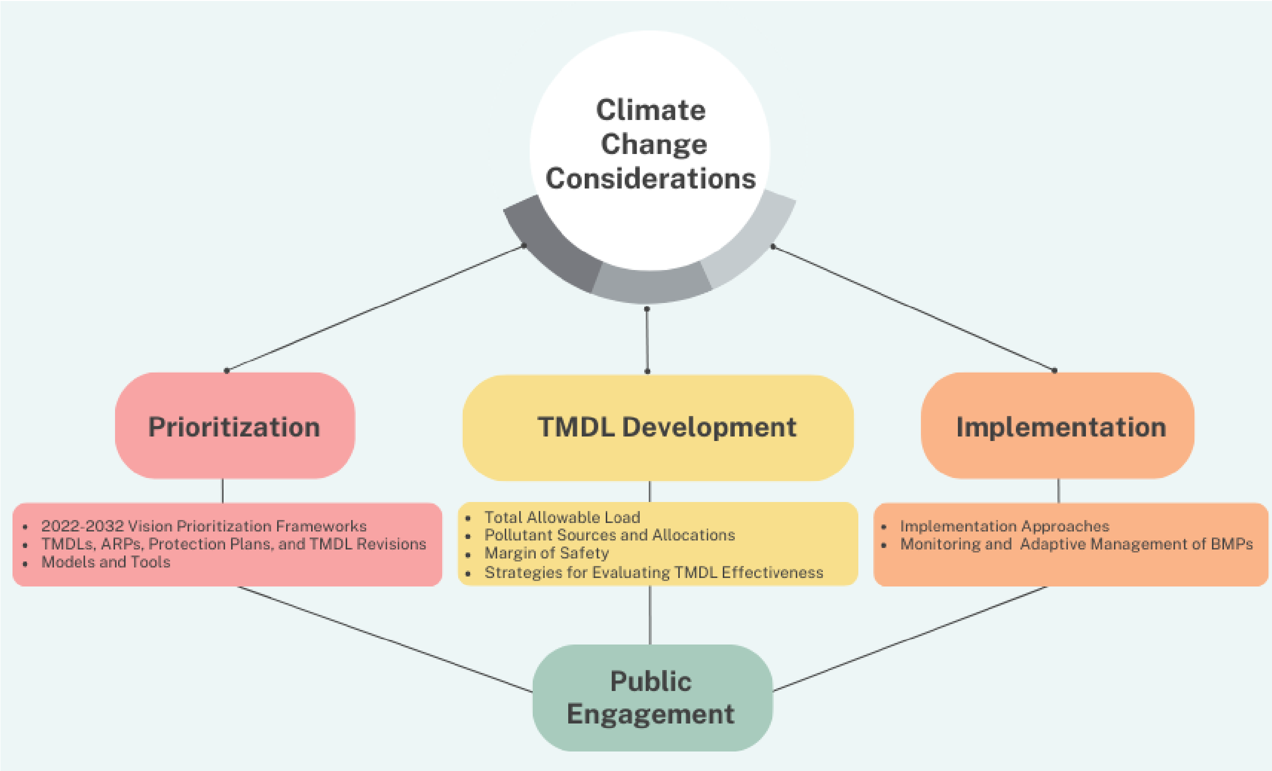
[11] When referring to entities that may implement CWA Section 303(d), this paper uses the phrase "states, territories and authorized Tribes." The term "authorized Tribes" in this paper refers specifically to Tribes that have obtained treatment in a similar manner as states, or TAS, authorization for CWA Section 303(d).

[12] CWA Section 303(d) lists include waters that are impaired or threatened and still require a total maximum daily load. The definition of "water quality limited segment" in the EPA's regulations implementing CWA Section 303(d) at 40 C.F.R. Section 130.2(j) includes waters "not expected to meet applicable water quality standards," which the EPA refers to as "threatened" waters.

[13] CWA Section 303(d)(1)(C).

[14] *Id.*; 40 C.F.R. Section 130.7(c)(1).

Figure 1: Climate Change Considerations for TMDL Processes



Prioritization

The 2022 Vision for the CWA Section 303(d) Program[15] communicates the expectation that states, territories and authorized Tribes engage in a long-term planning process and document their intentions in a Prioritization Framework. The Prioritization Framework is a planning document that serves two key purposes: (1) to describe long-term Vision priorities for development of TMDLs, other restoration plans and protection plans and a rationale for selecting those Vision priorities; and (2) to outline a general strategy for implementing the Goals of the 2022 Vision over the next decade. The EPA has developed — in coordination with states, territories and Tribes — a metric for the extent of priority waters addressed by TMDLs and other restoration plans in impaired waters or by protection approaches in healthy waters, reported in two-year increments.[16] Priority waters identified by states, territories and authorized Tribes consistent with these long-term Vision Prioritization Frameworks will be included in this metric. The 2022 Vision also includes a focus area on climate change considerations that notes

[15] See the 2022-2032 Vision for the Clean Water Act Section 303(d) Program. The program Vision includes a climate change focus area, which highlights the opportunity to "consider the impact of changing environmental conditions when developing and implementing TMDLs, and other restoration and protection plans; and the ability of plans to achieve and maintain water quality standards."

[16] See U.S. EPA, Information Concerning 2024 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions at 4. EPA recognizes that many states have developed or are in the process of developing their Vision Prioritization Frameworks. Accordingly, EPA and states discussed opportunities to integrate climate change considerations into prioritization at national trainings, in developing the Vision, in identifying priority waters for the metric every two years, and in developing this paper and in other contexts.

opportunities to “identify and utilize tools/resources that support prioritization of waters that may be particularly susceptible to changing climate conditions for protection and restoration.” In addition, the statute and regulations require that 303(d) list submittals must include a priority ranking for all listed water quality-limited segments still requiring TMDLs, accounting for the severity of pollution and the uses to be made of such waters, and specifically identify waters targeted for TMDL development in the next two years.[17]

These planning processes provide an opportunity to consider climate change impacts while affording appropriate flexibility to decide where to focus resources and efforts across all programmatic activities. The scope of these efforts could focus on specific geographic areas, pollutants, designated uses, pollutant-use combinations, additional considerations or some mixture of these aspects. Areas of emphasis that consider climate change impacts could include: waterbodies or uses that are most resilient or most vulnerable (e.g., waters with endangered species); where pollutant sources are rapidly increasing and may be exacerbated by climate change (e.g., harmful algal blooms); where funding can be leveraged for restoration (e.g., rebuilding floodplains for mutual benefit of water storage/flood mitigation in partnership with disaster mitigation funding); or waterbodies in communities already experiencing disproportionately high adverse impacts, including cumulative impacts, consistent with the EPA’s commitment to environmental justice.[18] Prioritization processes provide states, territories and authorized Tribes the opportunity to coordinate with multiple programs and stakeholders to determine how to use resources to incorporate climate change considerations strategically, for example, through coordinated monitoring plans and modeling and implementation strategies. In addition to the development of prioritization frameworks, these considerations are valuable for continued water quality planning prioritization efforts.

In addition to considering climate change impacts in deciding how to prioritize TMDLs for impaired waters, incorporating climate change considerations into the prioritization processes of other water quality planning documents and implementation activities is encouraged. Protection plans can improve water quality, help to mitigate or prevent climate-related impairments, and reduce downstream restoration challenges and costs. A state, territory or authorized Tribe may determine that rapid solutions are beneficial or practicable prior to TMDL development in areas where pollutant sources and solutions are clear; in such cases the expedient development and implementation of an advanced restoration plan may be suitable. TMDL developers could also consider climate change while prioritizing TMDL revisions.

Prioritizing TMDLs, other plans and implementation work in watersheds where agencies and partners are working on climate-related issues — such as fire prevention and recovery, shoreline stabilization, riparian buffer inclusion and widening, flood mitigation, temperature-sensitive species and implementation of green infrastructure — could help to invest resources effectively, leverage funding for project implementation and provide additional environmental benefits for ecological health and climate resiliency.

[17] CWA Section 303(d)(1)(A); 40 C.F.R. Section 130.7(b)(4).
[18] U.S. EPA, Information Concerning 2024 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions.

Various resources are available to assist states, territories and authorized Tribes with incorporating climate change considerations into prioritization of impaired waters for TMDL development and implementation, including modeling and online mapping and data tools. A selection of resources is listed below with examples of how each has been used.

Existing modeling efforts (e.g., HSPF, SWAT and QUAL2K) may be used to help assess the potential implications of climate variability and change on water quality and watershed systems.

> **Example:** The Minnesota Pollution Control Agency conducted a watershed analysis that considered in-stream temperature sensitivity to climate change. To address stream vulnerability to climate change, the state developed protection strategies starting with a HSPF model application, projecting future climate conditions with a focus on maximum water temperatures in July.[19] The state considered the stress and lethal temperatures for the native brook trout inhabiting streams of concern. When comparing historical scenarios with a 2040 model scenario, the state saw the projected increases in temperatures were causing more streams to approach the brook trout's lethal threshold. The state identified three streams that are projected to maintain the lowest in-stream temperatures and prioritized these streams for implementation of protection practices. To improve the microclimate and effective stream shade and to prepare for future climate change impacts, the state recommends protecting the floodplain and riparian corridor canopy and understory of these three streams.[20]

The EPA developed the Restoration and Protection Screening, or RPS, tool to inform management decisions by providing a flexible, user-driven approach for comparing watersheds based on environmental, stressor and social indicators, including several focusing on climate change-related impacts (e.g., projected change in annual temperature or projected change in summer precipitation).

> **Example:** The Utah Department of Environmental Quality utilized a stakeholder survey of top state water quality values and concerns in conjunction with the RPS tool to set priorities for TMDL development as part of the 2013 CWA Section 303(d) Vision.[21] For the 2022-2032 Vision Prioritization Framework, the state incorporated climate change into its prioritization process for restoration and protection plans, including TMDLs. Among other factors, RPS indicators were used to consider areas where flow reductions could impact water quality, permits may be affected by dwindling receiving waters, and wildfire could impact water quality.

> **Example:** The Wisconsin Department of Natural Resources identified key attributes of healthy watersheds and high-quality waters using the EPA's Preliminary Healthy Watershed Assessment and RPS tools to model healthy watersheds.[22] This initiative identified the healthiest

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[19] MPCA. Final Duluth Urban Area Watershed Restoration and Protection.
[20] *Id.*
[21] UDEQ. 2016. Prioritizing Utah's 303(d) List.; U.S. EPA. 2013. A Long-Term Vision for Assessment, Restoration, and Protection under the CWA Section 303(d) Program.
[22] WDNR. Modeling and Identification of Watersheds (Healthy Watersheds) and Water Bodies (High-Quality Waters) for Water Resources Protection Purposes in Wisconsin.

watersheds statewide to prioritize for protection, and the analysis included climate change projections for summer air temperatures as one of the stressors.[23]

Many additional online resources are available to assist with prioritization by providing climate impact visuals and mapping tools by region or specific location, including:

- The EPA's Climate Change Adaptation Resource Center (ARC-X);
- The EPA's How's My Waterway Extreme Weather tab;
- Climate Mapping for Resilience and Adaptation (Interagency Partnership);
- U.S. Climate Resilience Toolkit (Interagency Partnership);
- NOAA State Climate Summaries;
- Climate Engine (Interagency Partnership);
- Climate Explorer (Interagency Partnership);
- The National Park Service Scenario-Based Climate Change Adaptation Showcase;
- The Fifth National Climate Assessment; and
- The USGS National Climate Change Viewer.

See Appendix A for summaries of these tools.

TMDL Development

Climate change considerations could impact nearly every aspect of TMDL development. Many states are already incorporating climate change considerations into TMDL development. The EPA evaluated[24] approaches that states and the EPA have used to address climate change within a TMDL. Discussion of climate change within the TMDL document (beyond the presence of the term) was identified for 14 states,[25] with five more in the process of incorporating climate change considerations into the TMDL document at the time of review.[26] The review found that the most common impairment for which climate change was discussed was temperature, with a significant number of nutrient TMDLs discussing climate change as well. The most common sections of the TMDL where climate change was discussed included loading capacity, MOS, adaptive management and implementation. The TMDL documents reviewed generally noted that the impacts of climate change would be an anticipated future condition or involve substantial uncertainty in the context of each specific TMDL.

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[23] Climate projections: Average Projected Change of Summer Air Temperature 2061-2090. The WDNR modeling team worked in collaboration with the EPA and Cadmus Group to develop this metric.

[24] The first study used Ask WATERS and the ATTAINS databases to identify TMDL documents (completed 2017 and earlier) that used the term "climate change." To assess more recent documents, ATTAINS was used to identify nutrient and temperature TMDL documents from 2018-2022 that included discussion of climate change. Input provided during CWA 303(d) national training meetings was also used to identify instances of states integrating climate considerations into TMDL development. All analyses should be viewed as exploratory and not comprehensive.

[25] California, Connecticut, Idaho, Massachusetts, Michigan, Minnesota, Montana, Nevada, New York, Oregon, Utah, Vermont, Washington and Wisconsin. The EPA acknowledges that its review may not have identified all states that have discussed climate change in TMDL documents and additional states may have discussed climate change considerations in responses to comments, other TMDL record documents or without reference to the specific term "climate change."

[26] District of Columbia, Kansas, Missouri, South Carolina and Virginia.

A discussion of mechanisms for states, territories and authorized Tribes to incorporate climate change considerations into the TMDL development process, consistent with statutory and regulatory requirements, is provided below. This section also provides examples from the EPA's review of EPA-approved or EPA-established TMDLs. This discussion is not intended to be exhaustive and other mechanisms may be identified in the future. If climate change may impact attainment of water quality standards, or WQS, TMDL developers should provide a reasoned discussion of how climate change is considered in the TMDL document, as relevant and appropriate. As it would evaluate consideration of any relevant technical information, the EPA will evaluate the reasonableness of how a TMDL developer considered information regarding climate change impacts in determining whether a TMDL meets requirements.[27]

Establishing the Total Allowable Load

A TMDL must identify the loading capacity of a waterbody for the applicable pollutants.[28] EPA regulations define loading capacity as the greatest amount of a pollutant that a water can receive without violating WQS.[29] As part of the analysis of loading capacity, TMDLs must take into account critical conditions.[30] TMDLs also specify the methods used to establish the cause-and-effect relationship linking the numeric target and the identified pollutant sources, which may include water quality models. Climate change considerations for critical conditions and technical approaches for linkage analysis are provided below, along with examples.

TMDL developers should explain how climate change information is considered in developing loading capacities, as relevant and appropriate, in the context of other considerations in TMDL development and implementation. For example, in particular circumstances, TMDL developers might find it appropriate to set loading capacities based on current conditions while accounting for climate change considerations in other elements of the TMDL, such as the margin of safety, implementation, adaptive approaches or a combination of these elements. In other cases, a TMDL developer might find it reasonable to set loading capacities that account for both current and reasonably projected future conditions as part of an overall approach for taking climate change into account.

Critical Conditions

TMDLs must take into account critical conditions for stream flow, loading and water quality parameters as part of the analysis of loading capacity.[31] The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards.[32] Critical conditions for a TMDL typically depend on applicable water quality standards, characteristics of the observed impairments, source type, the pollutant and its interactions, hydrology, water level and waterbody type. As relevant and appropriate, TMDL developers should consider climate scenarios for current and future critical conditions.

[27] 40 C.F.R. Sections 130.7(c) and (d).
[28] CWA Section 303(d)(1)(C); 40 C.F.R. Sections 130.2(f) and (h), 130.7.
[29] 40 C.F.R. Section 130.2(f).
[30] 40 C.F.R Section 130.7(c)(1).
[31] *Id.*
[32] U.S. EPA. 1999. Protocol for Developing Sediment TMDLs.

One approach for analyzing climate-related impacts on critical conditions is to consider changes in critical-flow when determining allowable loads of pollutants, based on the assumption that critical-flow conditions result in the greatest impact to the assimilative capacity in the receiving waters. Climate change has already impacted critical-flow conditions, with many sites in the United States experiencing changes in seven-day low flows. While there is variation within regions, between the years 1940 and 2022 seven-day low flows[33] generally increased in the Northeast and Midwest such that, on the days of lowest flows, streams in these areas are carrying more water than before.[34] Low flows have generally decreased in parts of the Southeast and West, thus streams are carrying less water than before. Prolonged periods of less precipitation are predicted for much of the Western United States.[35]

Given that all areas of the United States are already experiencing the impacts of climate change, historical climate data may not accurately represent current or near future climate conditions. Analyzing critical stream flow conditions (e.g., 7Q10, 4Q3 or a load duration curve) to determine if the most recent 10 or 20 years of data are significantly different when compared to the full record may provide a fuller picture of potential near future climate conditions.[36] Similarly, if the critical conditions are based on high flow stormwater events, it would be important to determine if these events have increased in frequency or magnitude in recent years. If there have been changes in the critical conditions, use of more recent values, rather than the full historical record, could better reflect current conditions and conditions in the immediate future. If no significant differences between recent and historical records are observed, climate impacts may be less pronounced in this dataset.[37]

It may be appropriate for states, territories and authorized Tribes to investigate whether any recent studies of local climate conditions and impacts exist that can further inform their critical conditions analyses. National tools also may be helpful in this regard.[38] Watershed organizations and local academic institutions collect and compile meteorological and hydrological data, which can be useful for conducting critical condition assessments.[39]

Another approach could include examining a discrete time period where critical conditions occur to determine the allowable pollutant load. For example, when using a dynamic water quality model to estimate thermal loading, the model could focus on a single day or week during the modeling period where monitored conditions are the warmest and use the observed maximum daily temperature or maximum weekly average temperature for model calibration.

> **Example:** Climate change can affect the intensity and frequency of precipitation. Missouri is examining precipitation and flow datasets from the most recent 20 years, compared to the full historical record, to see if these datasets provide a better representation of current conditions

[33] For an EPA handbook on calculating low flow statistics, see Low Flow Statistics Tools, 2023.
[34] U.S. EPA. Climate Change Indicators in the United States. Streamflow. Accessed May 2022.
[35] NOAA. CMRA Drought Projections.
[36] *See, e.g.,* NOAA. NOAA Atlas 15 Note: tool is in development; IPCC AR6 Synthesis Report. Future Global Climate: Scenario-Based Projections and Near-Term Information, Chapter 4, 2023.
[37] Differences between recent data and the historical record are not necessarily indicative of climate change impacts and can be affected by confounding factors (e.g., dam construction, increased impervious cover, etc.).
[38] *See, e.g.*, US EPA. Streamflow Projections Map; US EPA. Dynamically Downscaled Ensemble; US EPA. LASSO Tool; additional examples provided in Appendix A.
[39] Example: Oregon State University's PRISM Climate Data.

for stream flow and runoff. For recent lake nutrient TMDLs, Missouri has begun developing a process that considers rain intensity and runoff by land cover type to estimate nonpoint source nutrient loading. Missouri is also considering any visible trends of increasing rainfall intensity or changes in flow regimes for potentially setting a loading capacity that reduces the likelihood of needing to revise future TMDLs.[40]

Technical Approaches
TMDLs are developed using a range of techniques, from simple mass balance calculations to complex water quality modeling approaches. The degree of analysis varies based on many factors, including the waterbody type, complexity of flow conditions, the pollutants causing the impairment and available resources. Even in circumstances informed by the best data, models and other analytical tools, uncertainty remains an inherent element of the TMDL development process. Climate change can introduce additional uncertainties to the data-based assumptions in TMDLs concerning hydrologic scenarios and influences on the pollutant being addressed. Therefore, it is important to describe uncertainties associated with climate change[41] and account for them in the TMDL document. Ideas for how to address these issues with mechanistic modeling and other approaches are included below.

Mechanistic Water Quality Models
TMDL developers may employ water quality models to understand current conditions and to evaluate a range of projected future conditions. Water quality models of varying detail and sophistication can be developed and used depending on the amount and quality of input data and information available, and with consideration that resource and data requirements increase in relation to model complexity. TMDL developers determine what approach to water quality modeling is most appropriate in each case, depending on the sources, waterbody and pollutants being addressed as well as the resources and data available. Previously developed water quality models can also be revisited as needed to predict potential climate change impacts through model scenarios or sensitivity analyses.

Water quality models can be useful tools to understand the key variables causing the water quality impairment as well as the impact climate change may have on critical conditions, wasteload allocations for permitted discharges, and non-point source load allocations. A model sensitivity analysis, which evaluates how the impact of a change in one or more input variables changes the output, should be performed to identify the inputs or processes more likely to result in a waterbody response. For a temperature impairment, for example, a sensitivity analysis may demonstrate that shade, flow or width to depth ratios singularly or in combination may have differing influences on stream temperatures. Model scenarios can then be performed to evaluate both the type and location of potential management measures under current and projected climate conditions. Appropriate use of such analyses will vary depending on the nature of applicable WQS and the condition of the waterbody.

Example: The EPA developed a model for the Columbia and Lower Snake Rivers Temperature TMDL (Washington and Oregon).[42] A synthesis of available scientific evidence indicated summer water temperatures in the Columbia and Snake Rivers have increased by approximately 1.5°C

[40] Missouri Department of Natural Resources. Thinking About Climate Change: Extending the Service Life of Our TMDLs.
[41] ELI. Climate Change and the CWA 303(d) Program.
[42] U.S. EPA. Columbia and Lower Snake Rivers Temperature Total Maximum Daily Load, August 2021.

since the 1960s. The River Basin Model, BM10,[43] considered temperature impacts to the Columbia and Snake Rivers from point sources, tributaries, dams, climate change and an agricultural water withdrawal. The model results were used to determine that climate-related temperature increases and dam impacts are the two dominant sources increasing river temperatures, with impacts that are an order-of-magnitude higher than point source dischargers, agricultural withdrawals and tributaries. Long-term model simulations (1970 – 2016) provide one line-of-evidence of a warming trend due to climate change in Columbia and Snake River temperatures in July through October. At three locations evaluated on the Columbia River, the estimated summer water temperature trend generally ranged from 0.3°C to 0.4°C warming per decade.

Example: The EPA developed a Lake Champlain (Vermont) SWAT model to project potential mid-century changes to watershed phosphorus loads with six different precipitation and temperature projections derived from global climate change models.[44] The model projected an overall average increase in phosphorus loading of approximately 30% for the period 2040 – 2070, assuming other factors remain the same. The TMDL noted that this projected increase likely overestimates the potential effect of climate change on the lake, because it does not take into account that, under these future scenarios, the loading capacity of the lake will be larger due to increased lake volume and flushing rates that will accompany the increased flows projected by the model. However, recognizing that the tributary loading analysis suggests climate change could increase phosphorus loads to the lake, Vermont included management measures in its Phase 1 Implementation Plan intended to minimize the phosphorus increases projected by the modeling. These measures included: best management practices to minimize phosphorus runoff during high intensity rainfall events, soil stabilization requirements, stream corridor policies to minimize streambank erosion even with a changing climate, and a comprehensive TMDL implementation tracking and reporting system.

Empirical Approaches

Complex water quality modeling efforts are not always necessary or feasible given resource or data availability. In appropriate situations, TMDL developers can account for climate-induced flow variations when calculating pollutant allocations by adjusting flow duration curves. FDCs portray the cumulative frequency of historical flow data over a particular time-period, relating flow values to the percent of time that those values have been met or exceeded.

The historical record may not be representative of evolving or anticipated climate conditions; therefore, historical, current or near future curves could be developed to compare the potential change in conditions associated with climate change. TMDL developers may begin with a review of the complete data record to evaluate whether flow changes are observed in the recent past and, if so, a determination of time periods that represent historical and current conditions. Near future flows can be estimated using climate projection tools.[45] Separate datasets can then be created for historical, current and near future timeseries and plotted on a single FDC. These plots can be used to describe change in conditions over time or a single timeseries can be selected for further analysis in the TMDL.

[43] U.S. EPA. River Basin Model 10 Fact Sheet.

[44] U.S. EPA. Phosphorus TMDLs for Vermont Segments of Lake Champlain, June 2016.

[45] *See, e.g.,* Climate Toolbox Future Streamflows

This comparison can also help identify whether flow duration curve adjustments may be useful for the waterbody of interest.

FDCs could be used to account for climate change by expanding the time period that is captured by the data. For example, some FDCs only account for the recreation or growing season and climate change may be affecting the length of those seasons. These flow conditions can be visualized and quantified by incorporating additional dates, outside of the defined season, into the FDC and comparing the defined timeseries with the expanded period. This process can be useful to discuss flow conditions associated with source assessment and implementation, but it does not consider specific fate and transport mechanisms associated with loading for certain pollutants.

FDCs could also be adjusted by adding intervals to help visualize the frequency and severity of disruptions such as droughts and big storms, as well as the timing and size of stream flow, enabling improved assessments of a stream's full range of possible flow conditions. When developing load duration curves,[46] which are visual representations of the relationship between stream flow and loading capacity, the use of additional flow intervals (i.e., flow ranges that incorporate greater or lesser flow magnitudes based on anticipated effects from drought or storm frequency) can support decision-making when determining allocations.[47] For example, separating a high flow interval into high flow and extreme high flow intervals facilitates evaluation of large storm events by defining and illustrating how these distinct conditions influence pollutant loading.

Pollutant Source Loadings and Allocations

TMDL development involves comprehensively identifying point and nonpoint sources of pollutants contributing to waterbody impairments. Climate change can impact the fate, transport and timing of loading from these sources, and TMDL developers should consider these potential impacts on loading and allocations. For example, larger or more frequent precipitation events may result in more extensive surface runoff of pollutants (e.g., nutrients, sediment, toxics), increased pollutant loads, diluted pollutant concentrations or impacts to assumptions underlying combined sewer overflow controls. Conversely, less frequent or lower amounts of precipitation may reduce runoff of pollutants or increase pollutant concentrations. A drought or change in timing of water availability can cause lower stream flows, exacerbating instream issues like increased temperatures and sediment aggradation. Seasonal variability may include prolonged growing seasons, thus increasing the duration of agricultural runoff. For point sources, increased precipitation can lead to larger runoff events that affect sources such as municipal separate storm sewer systems, combined sewer systems and concentrated animal feeding operations.

As part of TMDL development, the allowable load is divided among contributing sources with load allocations, or LAs, attributed to existing and future nonpoint and natural background sources and wasteload allocations, or WLAs, attributed to existing and future point sources.[48] Where human-caused climate change is introducing pollutant loadings (e.g., temperature) it should not be treated as

[46] U.S. EPA. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs, August 2007.
[47] ELI. Climate Change and the CWA 303(d) Program.
[48] 40 C.F.R. Section 130.2(g) and (h).

natural background, but instead as a source contributing to the total load.[49] Deciding how to divide the loading capacity among sources that comprise the WLA and LA can be a challenging task, with myriad considerations that may affect the allocation process.[50] Allocation schemes for WLAs and LAs that also consider relevant climate change factors are more likely to promote the long-term achievability of the TMDL. States may consider, for example, including in a TMDL a set of scenarios or alternative WLAs or LAs, along with appropriate triggers (such as those based on flow metering information or water quality data) that would prompt those alternative allocations to take effect.[51] Further, in determining allocation schemes, TMDL developers may consider identifying and addressing non-pollutant pollution impairments (e.g., impacts from hydrologic alteration), as appropriate.

Where relevant and appropriate, TMDL developers should provide a reasoned evaluation of the impact of climate change on permitted discharges when determining WLAs, especially WLA response to changes in precipitation and flow, and on nonpoint sources when determining LAs, as climate change is expected to have wide-ranging impacts on nonpoint sources of pollutants. Achievability of LAs may be influenced by factors such as a longer growing season or increasing precipitation. Feasibility of achieving nonpoint source reductions will inform the appropriate mix of WLAs and LAs in a TMDL.[52] For example, if a TMDL developer has information indicating nonpoint source loadings are expected to increase or LAs are expected to be more difficult to achieve with climate change, TMDL developers should consider such information in determining whether there is reasonable assurance that LAs will be achieved and account for it in determining the allocation scheme.[53] In addition, as the understanding of climate change impacts evolves or improves, TMDL developers should consider what changes and updates are needed to the TMDL allocations, so that the TMDL continues to be set at levels necessary to attain and maintain water quality standards (see sections on Strategies for Evaluating TMDL Effectiveness and Implementation).[54]

> **Example:** To address potentially prolonged growing seasons due to climate change, Michigan incorporated a year-round phosphorus target concentration, rather than a growing season target into the Ford and Belleville phosphorus TMDLs. [55] The TMDLs previously established phosphorus loading targets during the growing season (April-September) under the rationale that excessive phosphorus levels are expressed via algal blooms. Michigan revised this TMDL by

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[49] *See supra* note 42 Columbia River TMDL; U.S. EPA, Information Concerning 2008 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions at 10.

[50] Considerations that affect the allocation process include economics, feasibility, equitability, available data, types of sources and management options, public involvement, implementation, limits of technology, variability in loads, and effectiveness of BMPs. *See, e.g.*, US EPA, 1999. Protocol for Developing Nutrient TMDLs at 7-1.

[51] For an example of alternative WLAs, *see, e.g.*, State of Oregon Department of Environmental Quality. 2018. Western Hood Subbasin Temperature Total Maximum Daily Load.

[52] 40 C.F.R. § 130.2(i).

[53] EPA evaluates whether TMDLs addressing both point and nonpoint sources include reasonable assurance that WLAs and LAs will be achieved. *See, e.*g., CWA Section 303(d)(1)(c); 40 C.F.R. §§ 130.2(i), 130.7(c)(1). Where a TMDL identifies both LAs and WLAs, the TMDL depends on reasonable assurance that necessary reductions (e.g., through nonpoint source control measures or best management practices) will occur. The term reasonable assurance is used to describe approaches (e.g., authorities, actions or control measures) that, when implemented, are expected to achieve loads identified in a TMDL, including nonpoint sources in the TMDL's load allocation, consistent with the CWA and its implementing regulations.

[54] *See, e.g.*, 40 C.F.R. Sections 130.6, 130.7(c)(1).

[55] Michigan Department of Environment, Great Lakes, and Energy. 2019. Total Maximum Daily Load for Total Phosphorus in Ford and Belleville Lakes, Washtenaw and Wayne Counties.

court order and used the opportunity to establish annual loading targets rather than seasonal targets because of uncertainties in phosphorus loading in upstream lakes and reported heavy algal blooms in southern Michigan lakes in October and November. The duration of the algal growing season is expected to increase under current climate projections.

Margin of Safety

The CWA and associated regulations require that a TMDL include a MOS to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality.[56] When climate change contributes to this uncertainty, TMDL developers should provide a reasoned explanation of how climate change considerations are factored into an implicit or explicit MOS.

In an implicit MOS, an approach might be to understand the current climate conditions under which the impairment is occurring and consider how these conditions may be projected to change for the watershed (e.g., higher or lower flows, greater precipitation, higher temperatures, etc.). When using this approach, to account for additional uncertainty with climate change, the TMDL developer should make additional conservative assumptions in the TMDL analysis as necessary to incorporate projected watershed change. For example, a model could utilize a higher or lower runoff rate when determining precipitation-related runoff loads, or a lake model could include higher temperature assumptions in the lake to simulate algal growth.

If the MOS is explicit, it is helpful to consider how the loading capacity, if developed under current climate conditions, may change under future climate conditions. For example, an explicit MOS may be based on statistical uncertainty in the water quality modeling, or on projected flow or other environmental data projections that may impact pollutant loading or a waterbody's ability to meet and maintain WQS. States should provide a sound technical basis when using an explicit MOS as part of an approach for addressing uncertainties associated with climate change.

In the two examples below, states used the MOS as part of their broader approach to account for climate change in TMDLs.

> **Example:** Examples of implicit MOS can be found in the Fiddlers Cove and Rands Harbor Estuarine System TMDLs in Massachusetts.[57] Massachusetts developed TMDLs for the Cape Cod area that considered climate change through an implicit MOS. The TMDLs indicated that while the general vulnerabilities of coastal areas to climate change can be identified, specific impacts and effects of changing estuarine conditions were not well known. Because the science was not yet available, the state was unable to analyze climate change impacts on stream flow, precipitation and nutrient loading with any degree of certainty. Instead, the TMDL used an implicit MOS to address all sources of uncertainty, including climate change, based on conservative assumptions when developing the numeric model. These assumptions included: 1) the use of conservative monitoring locations that showed significant impairment, rather than sites that were just starting to show impairment; 2) target loads based on tidally averaged nitrogen concentrations on the outgoing tide, which is the worst case condition because

[56] CWA Section 303(d)(1)(C); 40 C.F.R. Section 130.7(c)(1).

[57] Massachusetts Department of Environmental Protection. 2017. Final Fiddlers Cove and Rands Harbor Embayment Systems Total Maximum Daily Loads for Total Nitrogen.

concentrations are at their highest; and 3) modeling analysis used conservative assumptions for nitrogen loads, in particular assuming that 100% of nitrogen is transferred and there is no attenuation of groundwater nitrogen sources to the estuary.

Example: An example of an explicit MOS is the Lake Memphremagog TMDL in Vermont.[58] This TMDL's MOS included a statement that "an additional 5% was added to the margin of safety based on modeling uncertainties described in detail in the TMDL modeling report, as well as uncertainties related to potential increases in flows and loading with climate change." This TMDL also noted that the "iterative implementation of the Lake Memphremagog TMDL also allows for adjustments to the implementation practices in future planning cycles as changes to precipitation and temperature regimes and their impacts on nutrient loading are better understood."

Strategies for Evaluating TMDL Effectiveness

Water quality management and adaptation strategies will need to respond to changing conditions and scientific understanding. TMDLs are often reflections of current conditions and available information about how current conditions may change. Additional evaluation of future conditions based on monitoring, modeling or other analysis could provide insight for when and how often it may be necessary to revisit a TMDL document or implementation approaches.

TMDL developers should include, as appropriate, a discussion on adaptive management where actions and activities are implemented, tracked and reviewed to determine effectiveness, and then additional actions and activities are revised and adjusted in response. This may warrant revision of the TMDL or further adjustment of the implementation actions. Regardless of the direction chosen, a process for how the TMDL or implementation approaches could be revised may be an important step in demonstrating TMDL effectiveness and provide the flexibility to incorporate additional information on changing climate conditions.

In many cases, accurately accounting for climate change will be difficult, as the impacts of climate change on pollutant loads are dependent on future projections, which are subject to their own uncertainties. However, this does not preclude consideration of climate change in TMDLs. Along with ways that climate change considerations can inform TMDL development (e.g., margin of safety, developing allocations, etc.), principles of adaptive management can be applied. For example, TMDLs can be revised to account for new information and prioritized for revision based on anticipated impacts of climate change. For those TMDLs where impacts from climate change are likely, the TMDL could include an explicit statement that the TMDL will be revisited at a certain time frequency (e.g., 10 years after approval, during the next basin monitoring cycle, on permit renewal cycles, etc.). Inclusion of a post-TMDL monitoring program (either separately or as part of the reasonable assurance/implementation approach) is a best practice that will help demonstrate whether the levels at which the TMDL are set continue to be the levels necessary to attain and maintain water quality standards and inform the need for adaptive management.

[58] Vermont Department of Environmental Cons. 2017. Lake Memphremagog Phosphorus Total Maximum Daily Load.

Implementation

Effective implementation plans or other approaches are important for achieving LAs and WLAs, whether as part of a TMDL document, permitting program, a CWA Section 319 nine-element watershed plan[59] or some other mechanism. In addition, the EPA recognizes that other relevant watershed and natural resource management programs (e.g., National Water Quality Initiative[60]) may also be useful in achieving load allocations.

In addition to several states specifically identifying climate mitigation in TMDLs and implementation efforts,[61] the practices that many states, territories and Tribes are already implementing offer additional environmental benefits in mitigating climate change effects on water quality and aquatic ecosystems. These practices include stream restoration projects (e.g., restoring channel morphology and flood plains, protecting and restoring riparian vegetation), green infrastructure (e.g., riparian buffers can provide pollutant loading reductions and carbon sinks)[62] and voluntary management actions coordinated with key stakeholders (e.g., timed flow releases from dams, in-stream flow leasing and drought management plans). These projects can also provide benefits for economic and social well-being like hazard mitigation and water storage, as well as leverage funding from other programs (see Montana example below).

Recent studies have examined climate change adaptive or resilient best management practices for addressing both WLA (stormwater) and LA implementation.[63] The EPA encourages states, territories and Tribes to not only address the impacts of projected climate change in their implementation approaches, but to also select implementation approaches that afford opportunities for adjustments. Johnson et al. (2022) notes "[p]ractices less sensitive to changes in climatic conditions will be more likely to function as intended as climate changes. More flexible/adaptable practices that can be revised or phased in over time provide a hedge against future risk." Adaptive management practices can also be used to "stress test" proposed plans over an array of potential future conditions, rather than trying to determine uncertain future conditions ahead of time; that information can be used to adjust implementation efforts as conditions change.[64] Additionally, implementing a wide range of activities may provide resiliency and additional environmental benefits, which can be considered in implementation and in establishing loads. Implementation approaches should involve an iterative process of implementing, monitoring and adjusting to be resilient enough to be effective across a broad range of future climate and watershed conditions.

> **Example:** The South Fork Nooksack River Temperature TMDL[65] in Washington is an example where the TMDL implementation plan evaluated climate change scenarios and identified a range of key implementation activities intended to improve water quality and achieve water quality standards. Simulations suggest that without any implementation efforts, maximum

[59] U.S. EPA. 2008. Handbook for Developing Watershed Plans to Restore and Protect Our Waters.
[60] NRCS: National Water Quality Initiative.
[61] ELI. Climate Change and the CWA 303(d) Program.
[62] See, e.g., U.S. EPA. 2024. Nonpoint Source Program and Grants Guidelines for States and Territories.
[63] Johnson et al. (2022) Journal of Water and Climate Change Vol 13 No 4, 1684 doi: 10.2166/wcc.2022.363.
[64] Fischbach et al. (2015) Managing Water Quality in the Face of Uncertainty, RAND Corporation.
[65] Washington State Department of Ecology. 2020. South Fork Nooksack River Temperature Total Maximum Daily Load. Publication No. 20-10-007.

water temperatures during critical summer low-flow conditions could increase by almost 6°C by the 2080s. Implementation activities identified in the implementation plan include restoring full system potential shade, addressing erosion and sedimentation, reconnecting floodplains and encouraging voluntary flow management. This combination of efforts aims to provide cold water refuges during high-temperature events and can likely provide substantial resiliency into the future that will help protect designated uses.

Example: The Montana Department of Environmental Quality completed a sediment TMDL for Ninemile Creek and several of its tributaries in 2005.[66] By implementing recommendations from the TMDL, the MTDEQ and local stakeholders are restoring natural stream processes to improve water quality while providing additional environmental benefits that mitigate floods, increase water storage and bolster aquatic habitat resilience to climate change. Ninemile Creek was channelized and disconnected from its flood plain due to historical mining practices. As a result, streambank erosion was accelerated, reducing habitat and increasing sedimentation. By reconnecting stream flows to the floodplain during spring runoff, groundwater contributions to the stream at baseflow have increased.[67] This information led to new partnerships with disaster mitigation agencies, including a $1.2 million FEMA Pre-Disaster Mitigation grant, and leveraged funds from the CWA Section 319 nonpoint source program as well as grants and other support from private, state and federal entities to fully reconstruct highly impacted reaches of the stream and increase cold water refugia for aquatic life.

Public Engagement

EPA policy is that there should be full and meaningful public participation in the TMDL development process. The TMDL regulations provide that the public process for TMDL prioritization and development be clearly described in the State Continuing Planning Process.[68] The TMDL regulations further provide that calculations to establish TMDLs shall be subject to public review consistent with the applicable State Continuing Planning Process.[69] Stakeholders are providing more comments regarding climate change, and it will become increasingly important for TMDL programs to be prepared to respond to climate-related questions and concerns about water quality when engaging with the public. Climate impacts will vary greatly by geographic region, and local stakeholders will often have valuable input about what these local impacts are, as well as effective approaches for addressing them. It is important to identify which issues affecting people at the local level are of the greatest priority, not only for TMDL development, but to keep residents and partners engaged for successful TMDL prioritization and implementation.

Certain communities and populations are uniquely and disproportionally vulnerable to watershed impairments and climate change impacts due to a variety of factors, including higher pollution burdens, greater exposure to environmental contaminants, lack of financial resources, limited access

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[66] Water Quality Restoration Plan and Total Maximum Daily Loads for the Ninemile Planning Area (2005).

[67] *See, e.g.*, Christine M. Brissette, Stream Restoration Effects on Hydraulic Exchange, Storage and Alluvial Aquifer Discharge, Graduate Student Theses, Dissertations, & Professional Papers 10992 (2017).

[68] 40 C.F.R. Section 130.7(a).

[69] 40 C.F.R. Section 130.7(c)(1)(ii).

to quality health care and other issues. These communities may want to understand how environmental programs, including the CWA Section 303(d) program, are addressing their concerns regarding climate change. States, territories and authorized Tribes are encouraged to target program resources and staff capacity towards areas and communities most impacted by changing climate conditions, as appropriate. More public engagement is needed in these communities so that they are well equipped to know how and when to engage in public processes.[70]

In addition, CWA Section 303(d) programs are encouraged to engage the public and other stakeholders using available public processes to inform, solicit feedback and enable constructive discourse to evaluate and address impacts of climate change transparently and clearly when carrying out CWA Section 303(d) program activities. In addition, the EPA encourages Tribes and states to collaborate on climate-related CWA Section 303(d) program issues of importance to Tribes. The EPA is responsible for ensuring meaningful government-to-government consultation opportunities with Tribes, consistent with the EPA Tribal Consultation Policy, when preparing for upcoming EPA actions on state lists of impaired waters and TMDLs that may impact Tribes or Tribal interests, including Tribal rights.[71]

Conclusion

Climate change can directly and indirectly affect water quality and raises important considerations for TMDL prioritization, development and implementation. While there can be considerable uncertainty about how climate change is impacting and will impact pollutant loadings and water quality in particular cases, there are aspects of the TMDL process where climate change can be considered. TMDL developers should document how they are evaluating climate change and related considerations, as appropriate. The EPA is committed to working with states, territories and authorized Tribes as they develop and implement TMDLs that meaningfully evaluate the impact of climate change on water quality and develop appropriate implementation measures. This document highlights several approaches that might be considered when prioritizing, developing and implementing a TMDL, however, this collection of approaches should not be considered limiting. The EPA encourages states, territories and authorized Tribes to explore a broad range of approaches for considering climate change when developing and revising TMDLs. Working together, the EPA and states, territories and authorized Tribes can advance the TMDL program by considering the impact climate change has had and will have on water quality to further protect human health and the environment.

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[70] The EPA's memorandum Information Concerning 2024 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions (pg. 24) includes a non-exclusive list of ideas for conducting outreach to meaningfully engage communities with environmental justice concerns throughout the monitoring, assessment and listing process, which may also be adapted for TMDL public processes.

[71] *See, e.g., id* at page 12; EPA. Consultation with Tribes.

Appendix A – Tool Descriptions

EPA Climate Change Adaptation Resource Center (ARC-X)
The EPA's Climate Change ARC-X is an interactive resource to help local governments effectively deliver services to their communities as the climate changes. Decision makers can create an integrated package of information tailored specifically to their needs. Once users select areas of interest, they will find information about: the risks posed by climate change to the issues of concern; relevant adaptation strategies; case studies illustrating how other communities have successfully adapted to those risks and tools to replicate their successes; and EPA funding opportunities.

EPA How's My Waterway Extreme Weather Tab
The How's My Waterway tab focusing on extreme weather shows current extreme weather events such as fires, floods and drought as well as modeled change in the occurrence of these events in coming decades. It also gives users the ability to overlay potentially vulnerable infrastructure and communities on top of the weather data.

EPA Dynamically Downscaled Ensemble (EDDE)
The EDDE is a collection of physics-based modeled data that represent historical and future atmospheric conditions under different scenarios. The EDDE dataset can be used to quantify regional and local changes to extreme weather and climate over the contiguous U.S. in a physically consistent framework with both high temporal and spatial resolution.

EPA Restoration and Protection Screening (RPS) Tool
EPA's RPS Tool provides an approach for comparing watersheds, their condition, and how well they may respond to management efforts. Originally, the RPS approach was developed to help prioritize waters needing TMDLs to reduce pollution and attain water quality standards. Many years of RPS application has shown that it can also support a wide range of other types of watershed comparisons across the United States, mainly because it can be customized to the user's specific needs. Users choose which watersheds to screen, from a few HUC12s to an entire state, and select indicators that are most relevant to their interests and screening objectives. Although more robust, time-consuming and expensive tools exist, RPS fills a niche as a rapid watershed assessment and comparison method at a general screening level. RPS is useful to numerous CWA and other programs, but its use is not an EPA requirement, nor does it constitute or modify EPA policies or program guidance. The RPS website provides access to the RPS Tool and associated indicator data, along with information and training resources for learning how to use the tool and data. RPS indicators related to climate change include:

- Projected Hydrologic Change
- Projected Precipitation Change
- Projected Air Temperature Change

EPA Locating and Selecting Scenarios Online (LASSO) Tool
The LASSO tool provides a step-by-step guide through the process of identifying and downloading climate change scenarios — or projections — that are relevant to specific interests or research questions. At each step the user will define criteria that will subset climate change information from a much larger archive, with LASSO providing helpful information and suggestions along the way. At the

end of the process the option is available to download maps, figures and GIS-ready spatial data, or use an interactive scatterplot widget to customize or change choices.

NOAA State Climate Summaries
NOAA's State Climate Summaries were initially produced to meet the demand for state-level climate information in the wake of the Third U.S. National Climate Assessment. This 2022 version provides new information and extends the historical climate record to 2020 for each state. The summaries cover assessment topics directly related to NOAA's mission, specifically historical climate variations and trends, future climate model projections of climate conditions during the 21st century, and past and future conditions of sea level and coastal flooding. Additional background information and links are provided.

Climate Mapping for Resilience and Adaptation (CMRA) (Interagency Partnership)
CMRA helps people assess their local exposure to climate-related hazards. Understanding exposure is the first step in determining which people, property and infrastructure could be injured or damaged by climate-related hazards, and what options might be available to protect these assets. Explore additional data that can help you understand exposure to climate-related hazards (extreme heat, drought, wildfire, flooding, coastal inundation).

U.S. Climate Resilience Toolkit (Interagency Partnership)
Learn about potential climate hazards and how to protect vulnerable assets with a steps to resilience guide, case studies and the Climate Explorer.

The Climate Explorer (Interagency Partnership)
Explore how climate is projected to change in any county in the United States. Shows climate maps and graphs, historical data and thresholds, and flooding for specific locations.

Climate Engine (Interagency Partnership)
Climate Engine tools use Google Earth Engine for on-demand processing of satellite and climate data on a web browser and features on-demand mapping of environmental monitoring datasets, such as remote sensing and gridded meteorological observations.

National Park Service Scenario-Based Climate Change Adaptation Showcase
A framework for working with climate uncertainty and preparing for a wide range of plausible future conditions.

U.S. Global Change Research Program: Fifth National Climate Assessment
The Fifth National Climate Assessment is the US Government's preeminent report on climate change impacts, risks and responses. It is a congressionally mandated interagency effort that provides the scientific foundation to support informed decision-making across the United States.

USGS National Climate Change Viewer
Interpreting output from many climate models in time and space is challenging. To aid in addressing that challenge, USGS has designed a viewer that strikes a balance between visualizing and summarizing climate information and the complexity of navigating the site.