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Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River under Future Climates using QUAL2Kw

Technology Transfer Webinar

Thursday, July 13, 2017

This webinar is based on the U.S. EPA report Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River (SFNR) under Future Climates using QUAL2Kw (EPA/600/R-14/233), available online at *https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=288533*. The Quantitative Assessment is designed to complement the temperature Total Maximum Daily Load (TMDL) Implementation Plan developed for the South Fork Nooksack River by Washington Department of Ecology in conjunction with EPA Region 10, the Lummi Nation, and the Nooksack Indian Tribe.

Background Information

Global climate change has the potential for significant impacts on freshwater ecosystems through changes in both the hydrological and thermal regime. Stream temperatures are projected to increase in most rivers, resulting in increased stress on cold water fish species such as salmon. Changes in hydrology, such as reduction in summer baseflows, could potentially exacerbate these impacts.

The Total Maximum Daily Load (TMDL) program, established by the Clean Water Act (CWA), has frequently been used to develop management plans intended to achieve temperature criteria and protect cold water fisheries. Most of these analyses, however, have been conducted using assumptions of a stationary climate under which historical data on flow and temperature can be assumed to be an adequate guide to future conditions.

EPA Region 10 and EPA's Office of Research and Development (ORD) and Office of Water (OW) launched a pilot research project to consider how projected climate change impacts can be incorporated into a TMDL and influence restoration plans, using the temperature TMDL for the South Fork Nooksack River (SFNR) in northwest Washington as the pilot. The SFNR is in Whatcom and Skagit counties and in an area considered typical of the mountainous, remote, forested landscape in that region, with minor urban and agricultural land uses along with extensive timber harvest and associated activities. The SFNR and its tributaries provide migration routes and spawning and rearing habitat for several salmon species throughout the year.

Fourteen SFNR mainstem segments and nine tributary segments are identified as being impaired by elevated temperature on Washington's 2010 303(d) list. These segments exceed the temperature criteria established to protect aquatic life uses for the support of cold water salmonid populations. The temperature TMDL identifies the issues and outlines the solutions needed to improve river temperatures.

The EPA Region 10 Climate Change and TMDL Pilot Research Plan (Klein et al., 2013; *https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=307737*) provided for the development of both a Quantitative Assessment and a Qualitative Assessment. The Quantitative Assessment (the subject of this webinar) uses the draft temperature TMDL Implementation Plan developed for the SFNR as the pilot for climate change analysis. It provides a comparison of modeled stream temperatures, with and without proposed allocations such as increased riparian shading, for critical conditions under projected climate conditions for the 2020s, 2040s, and 2080s. The companion Qualitative Assessment (*https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryID=320470)* is a comprehensive analysis of freshwater habitat

for Endangered Species Act (ESA) salmon restoration in the SFNR under climate change. Together, these assessments identify comprehensive actions to protect CWA beneficial uses (salmon habitat) and ESA Recovery goals under climate change. Please note that the focus of this webinar is the Quantitative Assessment.

A Step-by-Step Process

The Quantitative Assessment serves both as a place-based assessment of risks associated with climate change in the SFNR and as a "how to" example of technical methods that can be applied in temperature TMDLs at other sites, and, more generally, the evaluation of any temperature-sensitive watershed responses important to regulatory and planning applications.

As demonstrated in this example, the process of integrating climate change considerations into a TMDL need not involve a large cost. Where analytical tools that relate climate forcing to water quality outcomes (e.g., predicting water temperature response from meteorological time series) are already available from a business-as-usual TMDL linkage study, only a relatively small incremental effort is required to evaluate responses to future climate. The analysis is both practical and essential for the selection of mitigation and adaptation options that are likely to succeed while striving for low regrets relative to an uncertain future.

The basic steps for accomplishing a quantitative assessment of TMDL implementation plan sensitivity to future climate are summarized below. The details will vary from site to site and situation to situation, but the overall approach is robust and widely applicable.

1. **Water Quality Response Model** *(Slides 13-18)*: Most TMDLs will already have created a water quality response model that describes the linkage between stressor sources and impairments. For instance, in the State of Washington business-as-usual for temperature TMDLs is to apply the QUAL2Kw model to establish the linkage from shade, flow, and meteorology to water temperature responses. The user needs to ensure that the water quality response model contains climate-relevant variables. For example, a statistical model that predicted stream temperature from landscape variables without consideration of air temperature would not be suitable for evaluation of response to changing climate.

   Quantitative Assessment Report: *Section 2.1 describes the selection, development, and application of the QUAL2Kw model and accompanying Shade tool for the SFNR temperature TMDL.*

2. **Evaluate Critical Conditions** *(Slides 19-25)*: TMDL analyses should identify critical conditions for evaluating load allocations and wasteload allocations. These should be analyzed to determine the climate-related boundary conditions that are of significance to determining the relevant water quality outcome. For example, critical condition water temperatures in the SFNR are most sensitive to air temperature, tributary inflow temperatures, flow, channel dimensions, and shade. The first three inputs are climate-related boundary conditions that will need to be evaluated; the latter two sensitive factors are only indirectly influenced by climate and can be held to constant assumptions in the analysis.

   Quantitative Assessment Report: *Section 2.2 identifies the critical conditions for the SFNR TMDL, which consist of 7Q10 flows and 90th percentile 7-day average daily maximum air temperature (7DADMax air temperature).*

3. **Select Climate Scenarios** *(Slides 26-34)*: Watershed response analysis requires downscaled climate data at a spatial and temporal scale relevant to the process of interest. Many sources of such data are now available (see below). These include output from over 30 GCMs run under a variety of assumptions regarding greenhouse gas emissions in both the CMIP3 and CMIP5 modeling projects. In most cases it is not practical, nor is it necessary, to evaluate all the different model options. Instead, it is usually sufficient to select a small subset of models that cover the reasonably expected range of future conditions. We suggest using models that approximate the 10th percentile, median, and 90th percentile of key forcing functions such as air temperature and precipitation during the critical season. If local studies are not already available, the USGS National Climate Change Viewer (***http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp***) provides a good starting point. Keep in mind that it is not possible to provide a precise forecast of future climate; rather, we need to evaluate the reasonably expected potential range of climate to which adaptation may needed.

   Quantitative Assessment Report: *Section 3.1 presents the 3 selected scenarios. For three time horizons through the century (2020s, 2040s, and 2080s), approximate representation of low impact conditions (~10%) is provided by the CGCM3.1_t47 GCM, medium impact (~50%) by the CCSM3, and high impact (~90%) by the HADGEM1 GCM, all drawn from the A1B emissions scenario.*

4. **Derive Future Boundary Conditions** *(Slides 35-56)*: Step 2 identified the climate-related boundary conditions that need to be supplied to the linkage model. Estimating these inputs is the most involved step in the climate response analysis. In general these boundary conditions should not be specified directly from downscaled climate model output; rather, they should be applied to observed or estimated conditions used in the TMDL through a delta change approach. In this approach, the change predicted from current to future conditions by the climate model is applied to the site-specific data, thus avoiding systematic biases relative to the location of interest that may be present in the climate model. Changes for some of the climate-related boundary conditions (e.g., weather conditions) can be obtained directly from the downscaled GCM output. Changes in other factors (e.g., critical flow conditions) are available from gridded water balance models that have been developed to accompany several of the downscaled climate products (e.g., the VIC model application for the SFNR). Finally, site-specific derivations may be needed for some climate-related boundary conditions, such as the multiple regression model used to relate tributary water temperature to weather and landscape characteristics in the SFNR model.

   Quantitative Assessment Report: *Downscaled climate output for the SFNR watershed is described in Section 3.2, while Section 3.3 discusses information available from the VIC hydrologic model application that provides gridded estimates of flow response for each of the downscaled GCMs. Section 4 describes the details of developing the future boundary conditions, including the development of a regression model to estimate tributary inflow temperatures.*

5. **Apply Linkage Model** *(Slides 57-66)*: Analysis of the potential range of impacts under future climate is achieved by re-running the TMDL linkage model with the selected sets of future boundary conditions. As described above, these should include climate scenarios that encompass the range of potential responses. They should also include evaluation at several future time points, typically specified by 30-year windows of GCM output to suppress the impacts of annual to decadal cycles in weather. The same output as is used in the TMDL analysis should be collected for each model run.

   Quantitative Assessment Report: *Section 5 describes the application of the QUAL2Kw model under future climate forcing. After recapitulating the critical condition assumptions in Section 5.1, the corresponding future climate responses are summarized in Section 5.2. Sections 5.3 – 5.5 provide auxiliary supporting analysis of model sensitivity, application to the less restrictive 7Q2 flow condition, and an analyses of potential future changes in the flood regime.*

6. **Evaluate Implications** *(Slides 67-71)*: Comparison of the results obtained in Step 5 to the original TMDL model results identifies the range of potential changes that could occur in response to future climate. This information is relevant to the evaluation of the TMDL margin of safety, long-term planning for protection of the resource, and the selection of robust implementation options.

   Quantitative Assessment Report: *Section 6 describes potential implications of the study findings for the TMDL and associated implementation plans.*

Supplementary Information

In addition to the Quantitative Assessment itself, links to a variety of related resources are provided below.

Projected Climate Change Impacts on Cold Water Fisheries in the Pacific Northwest:

Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2011. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. *Climatic Change.* doi:10:1007/s10584-011-0326-z. ***https://link.springer.com/article/10.1007/s10584-011-0326-z***.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change*, 102:187–223. ***https://link.springer.com/article/10.1007/s10584-010-9845-2***.

Wu, H., J.S. Kimball, M.M. Elsner, N. Mantua, R.F. Adler, and J. Stanford. 2012. Projected climate change impacts on the hydrology and temperature of Pacific Northwest rivers. *Water Resources Research*, 48:W11530. ***http://onlinelibrary.wiley.com/doi/10.1029/2012WR012082/pdf***.

Littell, J.S., M. McGuire Elsner, L.C. Whitely Binder, and A.K. Snover, ed. 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate – Executive Summary in The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington, Seattle, WA. ***https://cig.uw.edu/publications/the-washington-climate-change-impacts-assessment-evaluating-washingtons-future-in-a-changing-climate-executive-summary/***.

Key Resources for Understanding Climate Change Trends, Projections, and Data:

Patte, D. 2014. Climate Trends and Projections – A Guide to Information and References. U.S. Fish and Wildlife Service Pacific Region. For a copy of the Guide, contact David Patte (*David_Patte@fws.gov*).

IPCC. 2013. *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324. *http://www.ipcc.ch/report/ar5/wg1/*.

Mote, P., et al. 2014. Climate Change Impacts in the United States, Chapter 21, Northwest (National Climate Assessment). *http://nca2014.globalchange.gov/report/regions/northwest*.

Sources of Fine-Resolution Downscaled Climate Projection Data:

Multivariate Adaptive Constructed Analogs (MACA) downscaled climate data: *http://maca.northwestknowledge.net*.

USGS Regional and Global Climate Data: *http://regclim.coas.oregonstate.edu/visualization/index.html*.

University of Washington Climate Impacts Group: *https://cig.uw.edu/*.

Bureau of Reclamation Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: *http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#Projections:%20Complete%20Archives*.

Empirical and Statistical Methods for Estimating Water Temperature Responses:

Dan Isaak's website on "Stream Temperature Modeling and Monitoring" at the U.S. Forest Service Rocky Mountain Research Station. *https://www.fs.usda.gov/ccrc/climate-projects/research/stream-temperature-modeling-and-monitoring*.

Flint, L.E., and A.L. Flint. 2011. Estimation of Stream Temperature in Support of Fish Production Modeling under Future Climates in the Klamath River Basin. Scientific Investigations Report 2011–5171. U.S. Geological Survey, Reston, VA. *http://pubs.usgs.gov/sir/2011/5171/pdf/sir20115171.pdf*.

QUAL2Kw Model, Documentation, and Associated Tools:

Ecology (Washington Department of Ecology). 2003a. QUAL2Kw.xls – A Diurnal Model of Water Quality for Steady Flow Conditions. Washington Department of Ecology, Olympia, WA. *www.ecy.wa.gov/programs/eap/models.html*.

Ecology (Washington Department of Ecology). 2003b. Shade.xls – A Tool for Estimating Shade from Riparian Vegetation. Washington State Department of Ecology, Olympia, WA. *www.ecy.wa.gov/programs/eap/models.html*.

Adaptation Strategies:

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2012. Restoring salmon habitat for a changing climate. River Research and Applications, doi:10.1002/rra.2590. *http://onlinelibrary.wiley.com/doi/10.1002/rra.2590/abstract*.

For More Information

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