Advancing Modeling Tools for Assessment of Long-Term Energy/Water Risks for Hydropower

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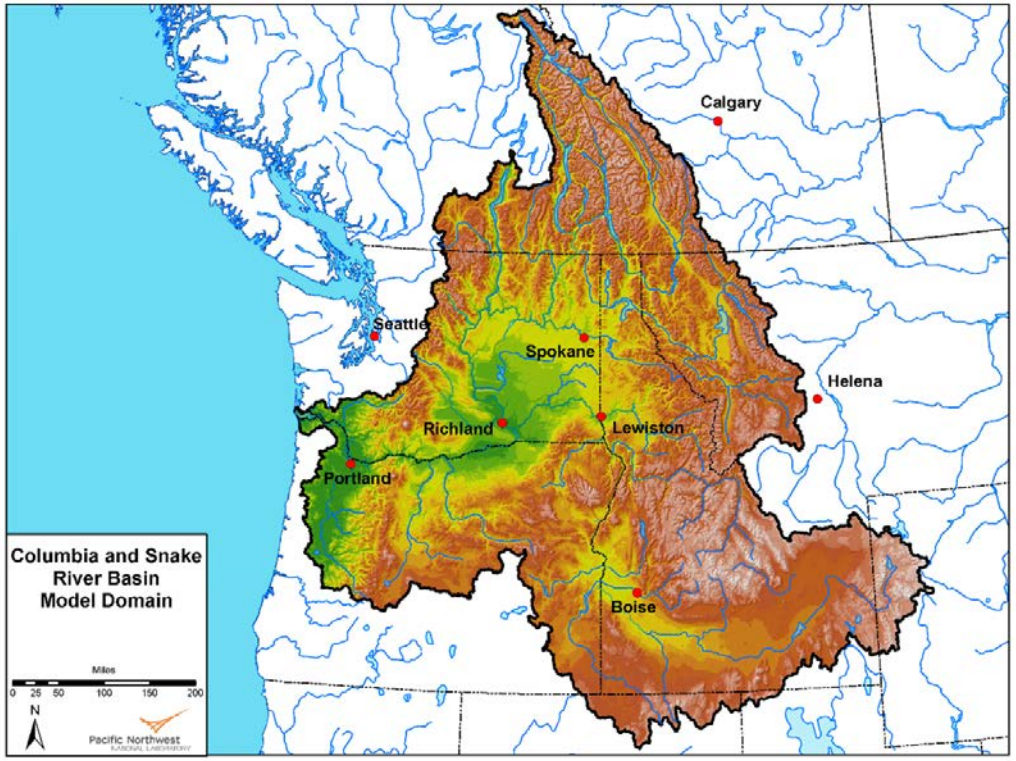

Hydropower Program

October 9, 2019

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Chief Scientist

Pacific Northwest National Laboratory

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

- The project is developing and demonstrating **a scalable, physics-based modeling framework** to better understand and evaluate hydropower investments and operational decisions in the face of changing hydrologic regimes.
- The advanced modeling framework, at the plant and system levels, can be used to evaluate the **potential likelihood and severity of water-temperature events** under a range of possible future scenarios and evaluate alternative operations and infrastructure investments to mitigate such events.

Project Objective & Impact

- **Advance the science, numerical modeling methods**, and demonstrate new capabilities that can be used to assess and mitigate potential future impacts to watershed-river-reservoir systems on streamflow, hydropower, thermoelectric power and water temperature under current and altered hydrologic regimes
- Delivering advanced modeling tools to research and management users
- High spatial detail of the models provides **a unique capability to examine critical issues in tributaries and mainstem reaches**, where land and hydro management can directly impact streamflow and temperature.

Project Information

Project Principal Investigator(s)

Mark Wigmosta

WPTO Lead

Simon Gore
Tim Welch

Project Partners/Subs

Project Duration

- 10/1/2016
- 9/30/2020

Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Environmental R&D and Hydrologic Systems Science

- Develop technologies and strategies that avoid, minimize, or mitigate ecological impacts
- Assess potential impacts of long-term hydrologic variations to hydropower generation and flexibility
- Better identify opportunities and weigh potential trade-offs across multiple objectives at basin-scales

- Advancing the state of the science around understanding water temperature events in the future for long-term infrastructure planning, energy-water nexus issues, and evaluation of hydropower operations and alternatives.
- Aligns with WPTO HydroWIRES initiative, particularly Area 3 to *"develop operational strategies and associated tools that enable hydropower to better optimize its operations to support evolving grid needs" and "quantify hydropower plant-and fleet-level contributions to system-level water availability, environmental flows, and other non-power but system-level goals."*

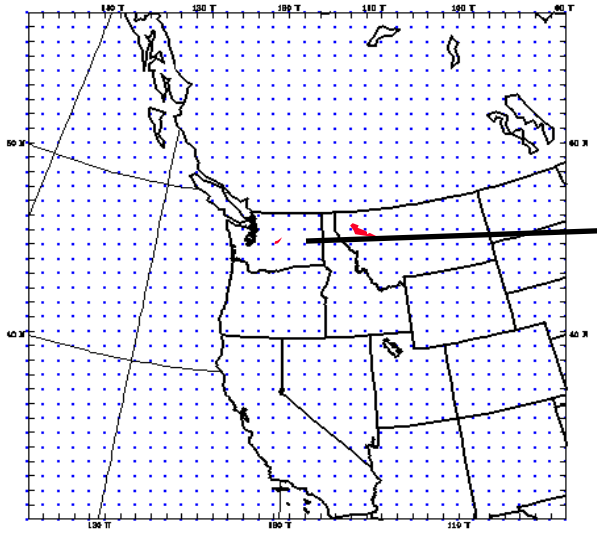
Project Budget

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Costed	Costed	Costed	Total Costed	Total Authorized
$749,003	$753,271	$298,600	$1,800,874	$2,111,001

Management and Technical Approach

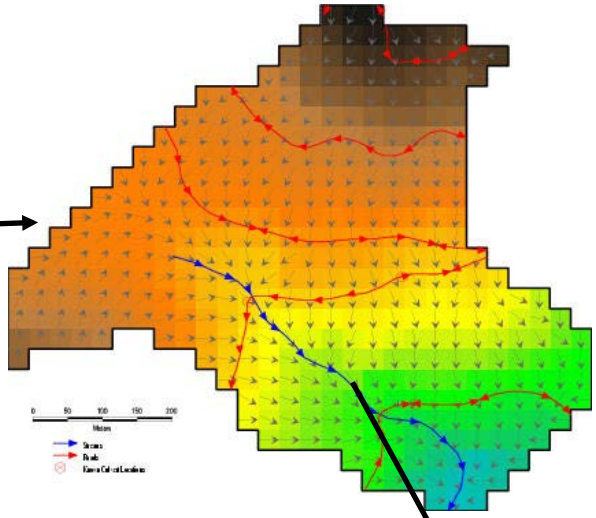
- The PNNL project team is led established researchers for each major technical area
- The project team communicates regularly with WPTO staff
- Regional Coordination
  - Regular conference calls and three on-site meetings with action agencies BPA, USACE, and BoR to coordinate activities
  - Stakeholder outreach to establish National Steering Committee (NSC) and Columbia Basin Stakeholder Groups.
- Communication with external users
  - Gain feedback on software
  - Identify and correct technical issues

Management and Technical Approach

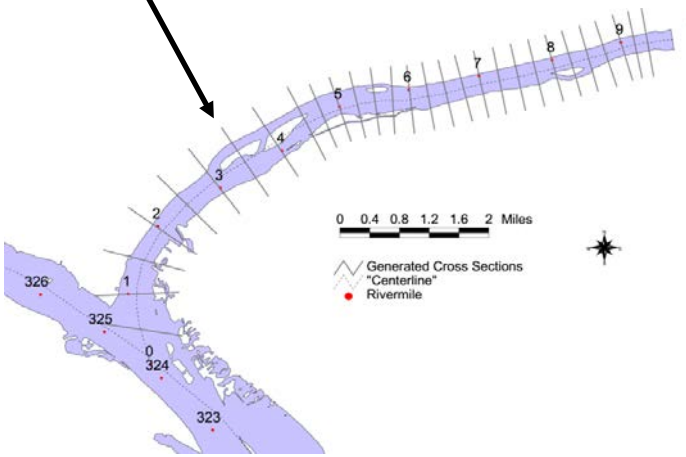


Regional Climate Model
WRF 6-km ensembles

DHSVM Distributed Watershed Model
90-m tributary streamflow & Temperature



MASS1 and MASS2
River Models



Management and Technical Approach

- **Climate Modeling:**
  - Ensemble approach using the Weather Research and Forecasting (WRF) model has been completed covering the entire Columbia Basin
  - Help capture the uncertainty of climate forecasts on tributary inflows and water temperature.
- **Watershed Hydrologic Modeling (DHSVM)**
  - Spatially distributed streamflow and water temperature at user-defined temporal and spatial resolutions
  - Enhance DHSVM to run on HPC systems (as well as multicore desktop systems)
  - Parallel version of the PNNL DHSVM that is open source (github site: https://github.com/pnnl/DHSVM-PNNL).

Management and Technical Approach

- **River and Reservoir Water Quality Modeling**
  - Models to simulate present and future water-temperature conditions at temporal and spatial scales high enough for users to access environmental conditions and ecosystem function questions
    - Variable resolution from 100s of km down to 10s of m
  - Key activity was integration of the PNNL MASS1 1D model with parallel DHSVM. Also, improvements to the 2D MASS2 model will be completed.
  - MASS1 and MASS2 will also be released as an open source codes (github sites: https://github.com/pnnl/mass1).

End-User Engagement and Dissemination Strategy

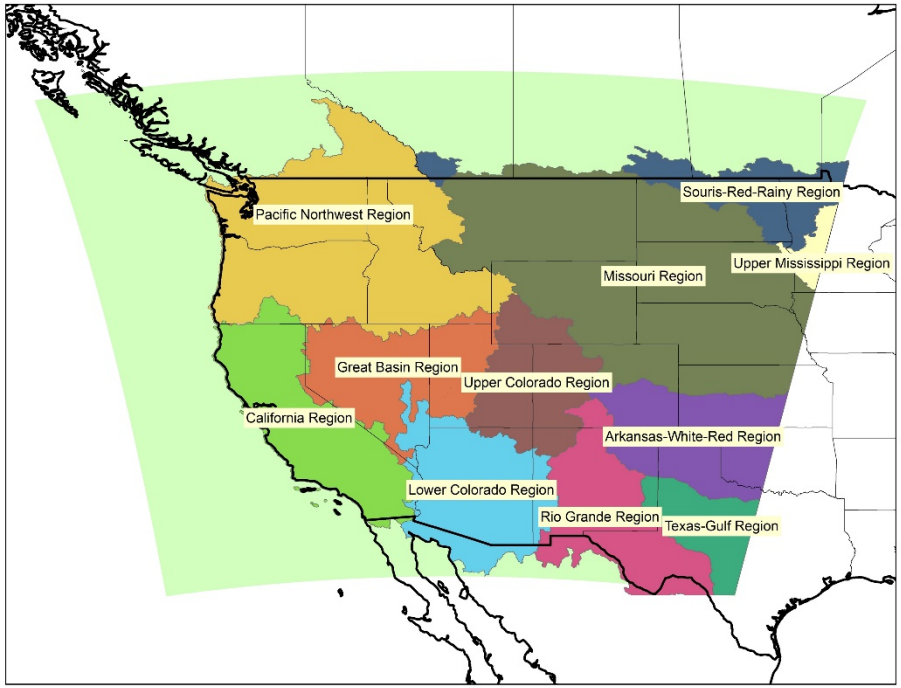
- End user engagement requires a multi-faceted approach; our communications and stakeholder engagement is being accomplished through:
  - Stakeholder interaction with the project National Steering Committee and Basin Stakeholder Groups
  - Conference calls and strategic face-to-face meetings with action agencies (BPA, USACE, and BoR) to coordinate activities in the Columbia River Basin
  - Peer reviewed publications
  - Technology transfer though open source software available to download

Technical Accomplishments

- The project has seen success over the FY17-FY19 period, including:
  - User needs assessment and national user group meeting at HydroVision 2017
  - Development and open source release of a new, parallel version of the DHSVM model
  - Integration of PNNL MASS1 with parallel DHSVM
  - Completion of high-resolution atmospheric modeling (using WRF) over the Western US at 6km resolution
  - Application of the modeling framework to the entire Columbia River Basin
  - Peer-reviewed publications

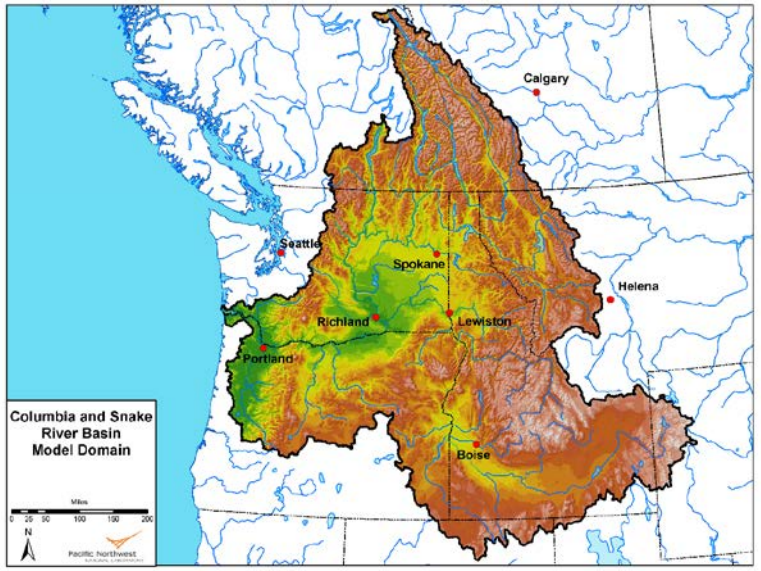
Technical Accomplishments (Cont.)

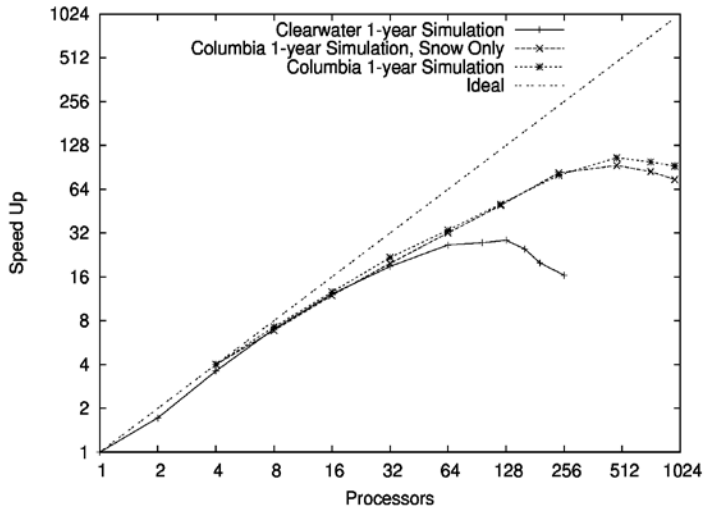
- **Climate Modeling.**
  - Historical WRF model runs have been completed at a 6-km resolution that cover the time period of 1981-2015
  - WRF model runs have been completed for the RCP8.5 scenario for the time period of 2041-2070.
  - This effort has resulted in two peer reviewed publications.
    - Note that these publications are collaborations between the current EERE project and DoD SERDP and DOE Office of Science projects



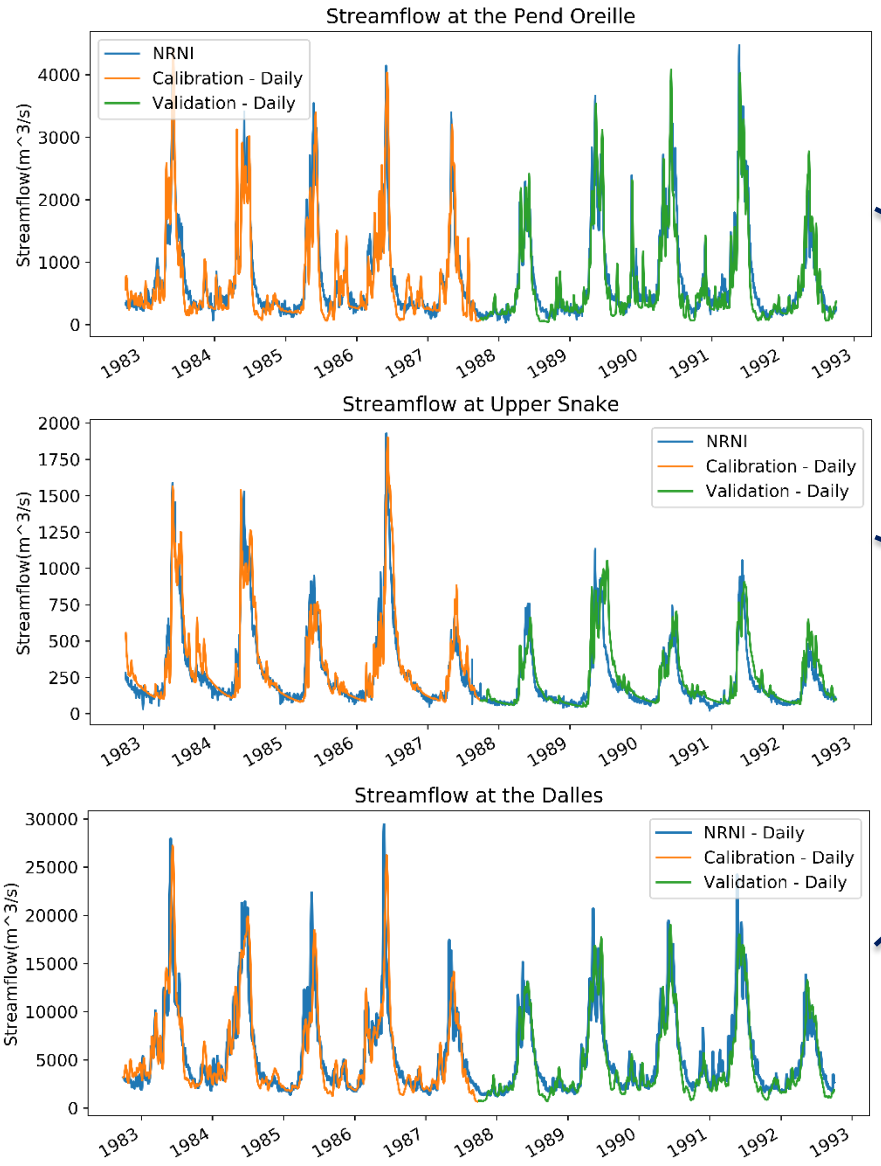
Technical Accomplishments (Cont.)

- **Watershed Hydrologic Modeling.**
  - Applied to the entire Columbia River Basin at 90-m spatial resolution resulting in about 83 million active cells and 20,800 stream segments.
  - One year simulation time was reduced from about 19 days with one processor to about 4 hours with 480 processors.
    - Allows for consideration of risk by using multiple ensembles and multiple management options
  - This parallel code effort is documented in a peer reviewed publication.
  - Parallel version being used at ORNL and multiple universities
  - Also, enabling an existing DOE project and an upcoming non-DOE funded project to optimize forest management to both reduce wildfire risk and improve streamflow related salmon habitat conditions.

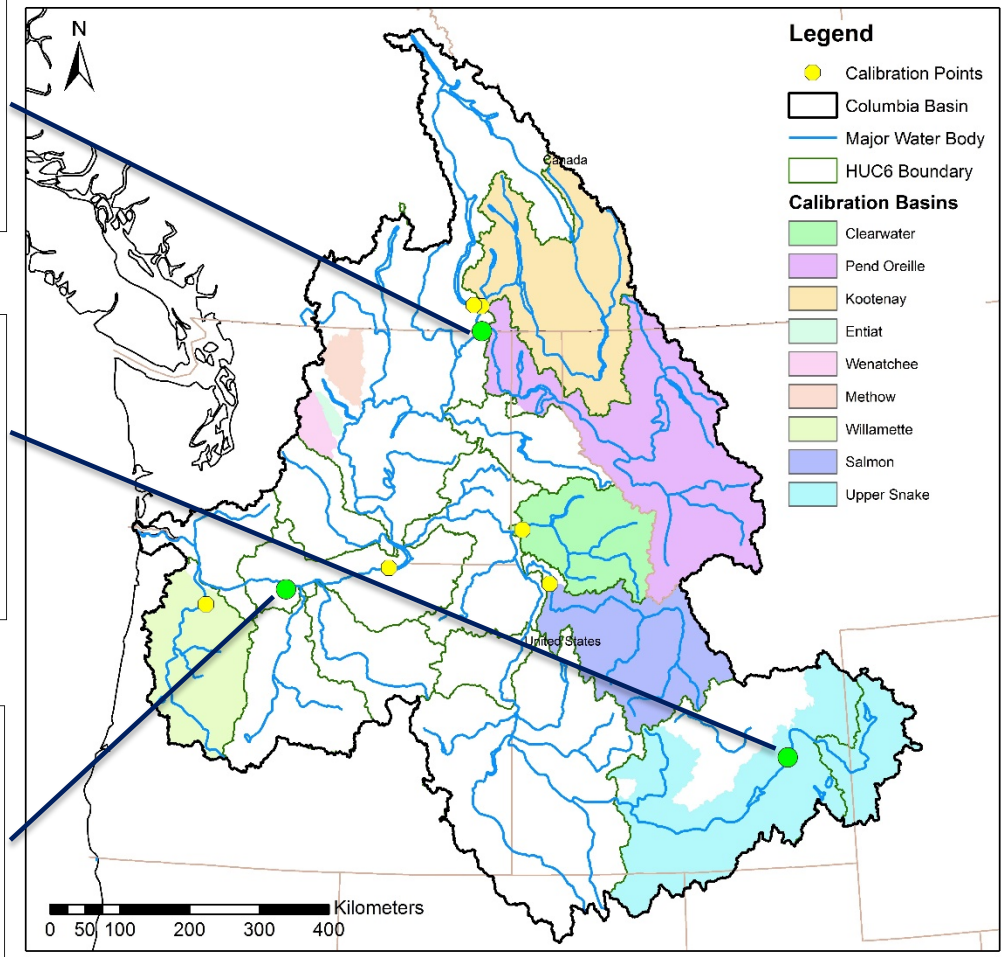




Technical Accomplishments (Cont.)



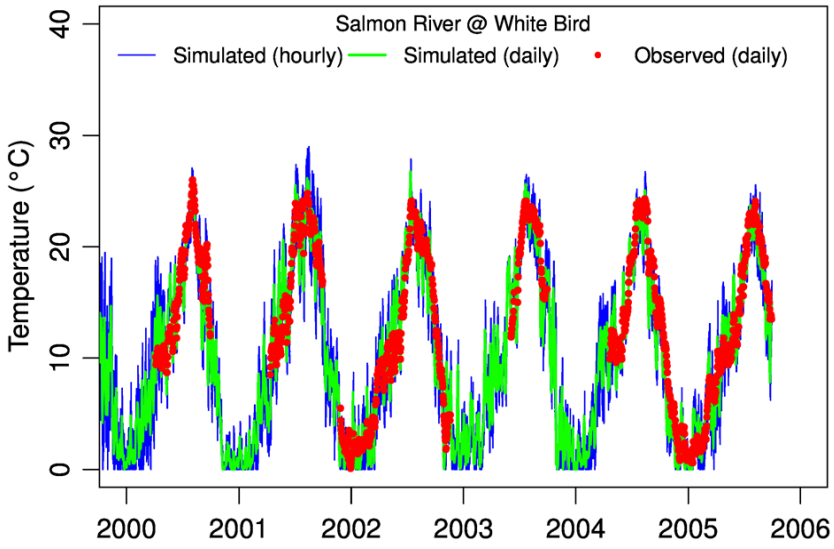
DHSVM Simulated Daily Discharge

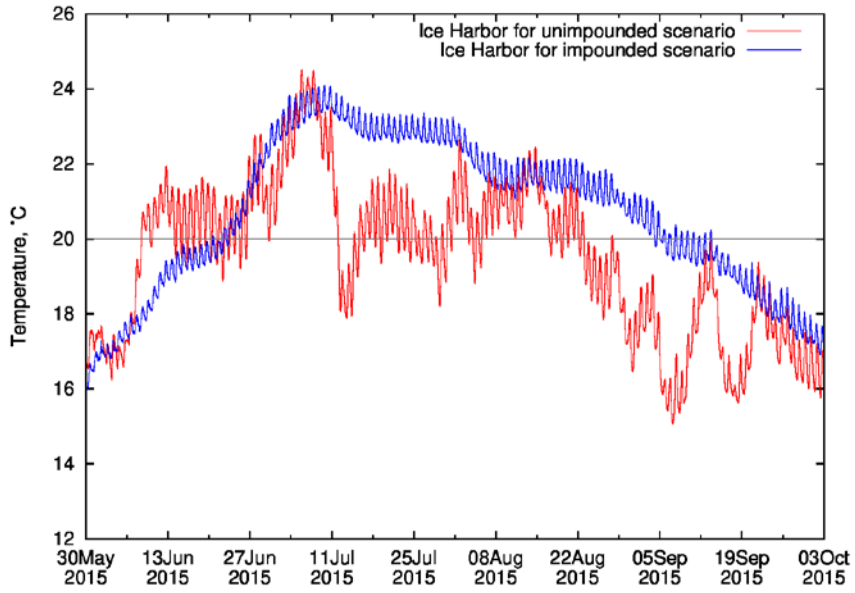


Calibration basins account for ~ 70% of discharge at the Dalles

Technical Accomplishments (Cont.)

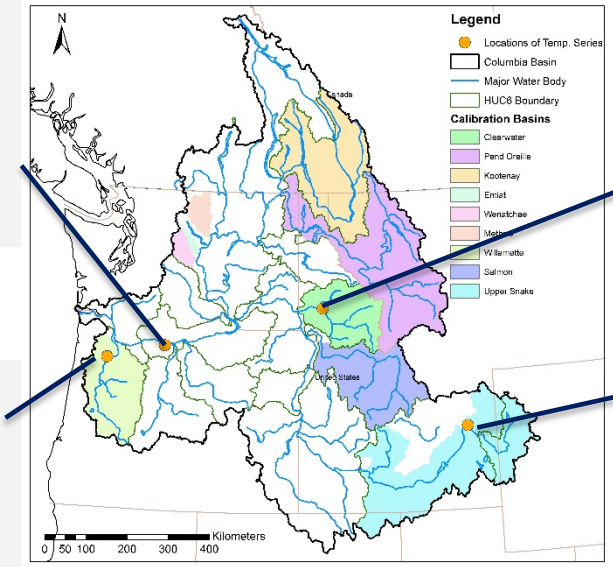
- River and Reservoir Water Quality Modeling
  - PNNL modular aquatic simulation system 1D (MASS1) unsteady hydrodynamic and water-quality model has been integrated into parallel DHSVM
  - Allows for simulation of complex channel hydraulics, hydro operations, and water temperature at any location in the channel network
  - Assess significant changes to hydro system configuration (e.g. impounded vs unimpounded)
  - Investigate the benefits of alternative hydro operations and infrastructure investments





Technical Accomplishments (Cont.)

Uncalibrated Simulated Daily Temperature Without Regulation



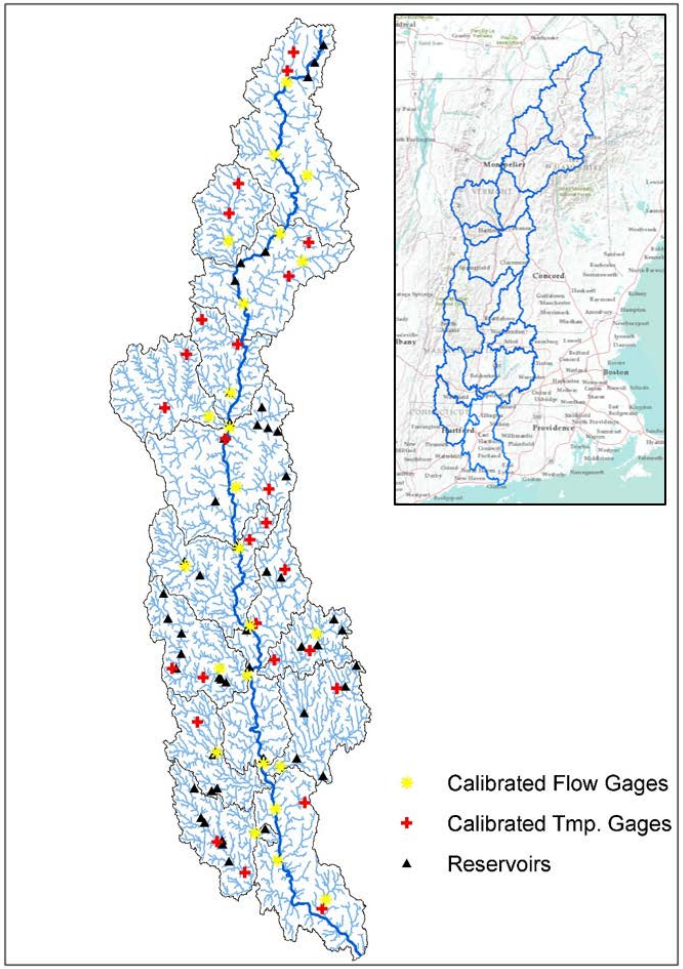
Technical Accomplishments (Cont.)

- Publications
  - Perkins W, Z Duan, N Sun, M Wigmosta, M Richmond, X Chen, R Leung. Parallel Distributed Hydrology Soil Vegetation Model (DHSVM) Using Global Arrays. 2019. Environmental Modelling and Software. Available online at: https://doi.org/10.1016/j.envsoft.2019.104533
  - Chen, Xiaodong, L. Ruby Leung, Yang Gao, Ying Liu, Mark Wigmosta, and Marshall Richmond. "Predictability of Extreme Precipitation in Western US Watersheds Based on Atmospheric River Occurrence, Intensity, and Duration." Geophysical Research Letters 45, no. 21 (2018): 11-693.
  - Chen, X., Leung, R. L., Wigmosta, M., & Richmond, M. (2019). Impact of Atmospheric Rivers on Surface Hydrological Processes in Western U.S. Watersheds. Journal of Geophysical Research: Atmospheres.
  - Sun N, Wigmosta M, Zhou T, Lundquist J, Dickerson-Lange S, Cristea N. 2018. Evaluating the functionality and streamflow impacts of explicitly modelling forest–snow interactions and canopy gaps in a distributed hydrologic model. Hydrological Processes;1–13. https://doi.org/10.1002/hyp.13150
- Software Release
  - DHSVM software github site: https://github.com/pnnl/DHSVM-PNNL
  - MASS1 software github site: https://github.com/pnnl/mass1
  - **Used by several research groups outside of PNNL**, including Oak Ridge National Laboratory, the University of Washington, Western Washington University, California Polytechnic State University, University of Utah, Texas A&M University, and the University of California, Los Angeles.

Future Work

- Early FY20 complete application of the modeling framework to the Columbia River Basin for the natural inflow case and regulated case under current and future climate to examine the relationship between current operations and mainstem water temperature.
- FY20 apply the modeling system to the Connecticut demonstration basin in the eastern US that will include thermoelectric power production.
  - Include thermal plant module
  - DHSVM hydrologic model will be driven by the MACAv2-LIVNEH climate data products a six kilometer resolution for historic conditions and the RCP8.5 scenario for the time period of 2041-2070
  - Identify locations at risk of high water temperature and examine potential changes to future operations and possible infrastructure enhancements to mitigate temperature concerns
- Provide model updates to external users

Future Work



- Connecticut Demonstration Basin
  - Large number of reservoirs
  - Available discharge and stream temperature data
  - Natural gas thermoelectric