

Quality Assurance Project Plan for Snake River - Hells Canyon Temperature TMDL Model Development

Contract EP-C-17-046
Task Order 1

Prepared for:

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February 24, 2022

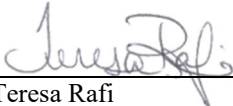
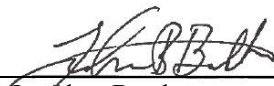
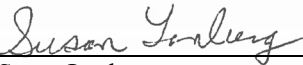
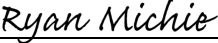
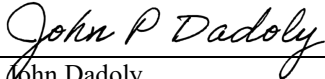
QAPP 563, Revision 3

This quality assurance project plan (QAPP) has been prepared according to guidance provided in the following documents to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use:

- *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5, EPA/240/B-01/003, U.S. Environmental Protection Agency, Office of Environmental Information, Washington DC, March 2001 [Reissued May 2006])
- *EPA Office of Water Quality Management Plan*. (EPA/821/R-09/001, U.S. Environmental Protection Agency, Office of Water, Washington DC, February 2009)
- *Guidance for Quality Assurance Project Plans for Water Quality Modeling Projects* (EPA 910-R-16-007, U.S. Environmental Protection Agency, Region 10, Office of Environmental Review and Assessment, Seattle, WA, December 2016)

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ACRONYMS AND ABBREVIATIONS

AWQMS	Ambient Water Quality Monitoring System (ODEQ)
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GPS	global positioning system
IDEQ	Idaho Department of Environmental Quality
IPC	Idaho Power Company
LCD	Local Climatological Data
LiDAR	Light Detection and Ranging
MGD	million gallons per day
NAVD88	North American vertical datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NLDAS	North American Land Data Assimilation System
NPDES	National Pollution Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
PRISM	Parameter elevation Regression on Independent Slopes Model
PSU	Portland State University
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RM	river mile
TMDL	total maximum daily load
TOCOR	Task Order Contracting Officer Representative
TOL	Task Order Leader
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USGS	United States Geological Survey
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plan

DISTRIBUTION LIST

This document will be distributed to the following U.S. Environmental Protection Agency (EPA), Oregon Department of Environmental Quality (ODEQ), and Tetra Tech staff involved in this project (Table 0-1).

Table 0-1. Snake River - Hells Canyon TMDL Development QAPP Distribution List

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SECTION I: PROJECT/TASK ORGANIZATION

I.A PURPOSE/BACKGROUND

The Snake River – Hells Canyon temperature TMDL is being developed by Oregon DEQ with technical support from EPA Region 10. This Quality Assurance Project Plan (QAPP) summarizes the overall organization of the water quality modeling work that will be conducted by Tetra Tech under contract with EPA Region 10 to support development of the Snake River - Hells Canyon temperature TMDL, as well as the roles, responsibilities, and lines of authority and reporting for those involved. The anticipated Snake River - Hells Canyon temperature TMDL project area includes the extent of the Snake River and Hells Canyon reservoir complex to include free-flowing segments of the river from the Oregon/Idaho border near Adrian, OR near river mile 409 to the state line between Oregon, Idaho, and Washington and river mile 176. The modeling to be conducted by Tetra Tech under contract with EPA Region 10 will also include the Snake River downstream of Oregon in Idaho and Washington to river mile 139.

A TMDL is a water quality restoration plan and the calculation of the maximum amount of a pollutant that a waterbody can receive while still meeting water quality standards for that particular pollutant. The maximum amount of loading a waterbody can receive is called the loading capacity. Loading from all pollutant sources must not exceed the loading capacity (TMDL) of a waterbody, including an appropriate margin of safety.

Load allocations are portions of the loading capacity that are allocated to background sources or non-point sources, such as urban, rural agriculture, or forestry activities. Wasteload allocations are portions of the total load, which are allocated to NPDES permitted sources, such as wastewater treatment plants or industries. Wasteload allocations are used to establish effluent limits in NPDES discharge permits. Allocations may also be reserved for future uses, called reserve capacity. Allocations are quantified measures that assure water quality standards will be met and may distribute the pollutant loads between nonpoint and point sources. This general TMDL concept is represented by Equation 1.

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{"Reserve Capacity"} + \text{MOS} \quad (\text{Equation 1})$$

Where $\sum \text{WLA}$ is the sum of wasteload allocations (NPDES permitted sources), $\sum \text{LA}$ is the sum of load allocations (nonpoint sources and background), Reserve Capacity is allocations reserved for future uses, and MOS is a margin-of-safety to account for uncertainty. For a temperature TMDL, these elements establish the maximum thermal loads that a waterbody may receive without exceeding applicable water quality standards for temperature designed to protect aquatic life and other beneficial uses. The Clean Water Act requires TMDLs be developed for waterbodies that do not meet water quality standards and are listed as water quality impaired on the State's 303(d) list.

The project management, quality assurance (QA) program, and modeling activities are included in this quality assurance project plan (QAPP). Duties and responsibilities of personnel for various aspects of the data compilation, model update and calibration, and reporting process are described along with an implementation schedule.

I.B ROLES AND RESPONSIBILITIES

The organizational aspects of the project outlined below provide the framework for conducting tasks related to the model update. The organizational structure and function can also facilitate project performance and adherence to quality control (QC) procedures and QA requirements. Key project roles are filled by those persons responsible for ensuring that model setup uses valid data and procedures, and the persons responsible for approving and accepting final products and deliverables. The project organizational chart is presented in Figure I-1 and includes relationships and lines of communication among all participants and data users. The responsibilities of these persons are described in Table I-1.

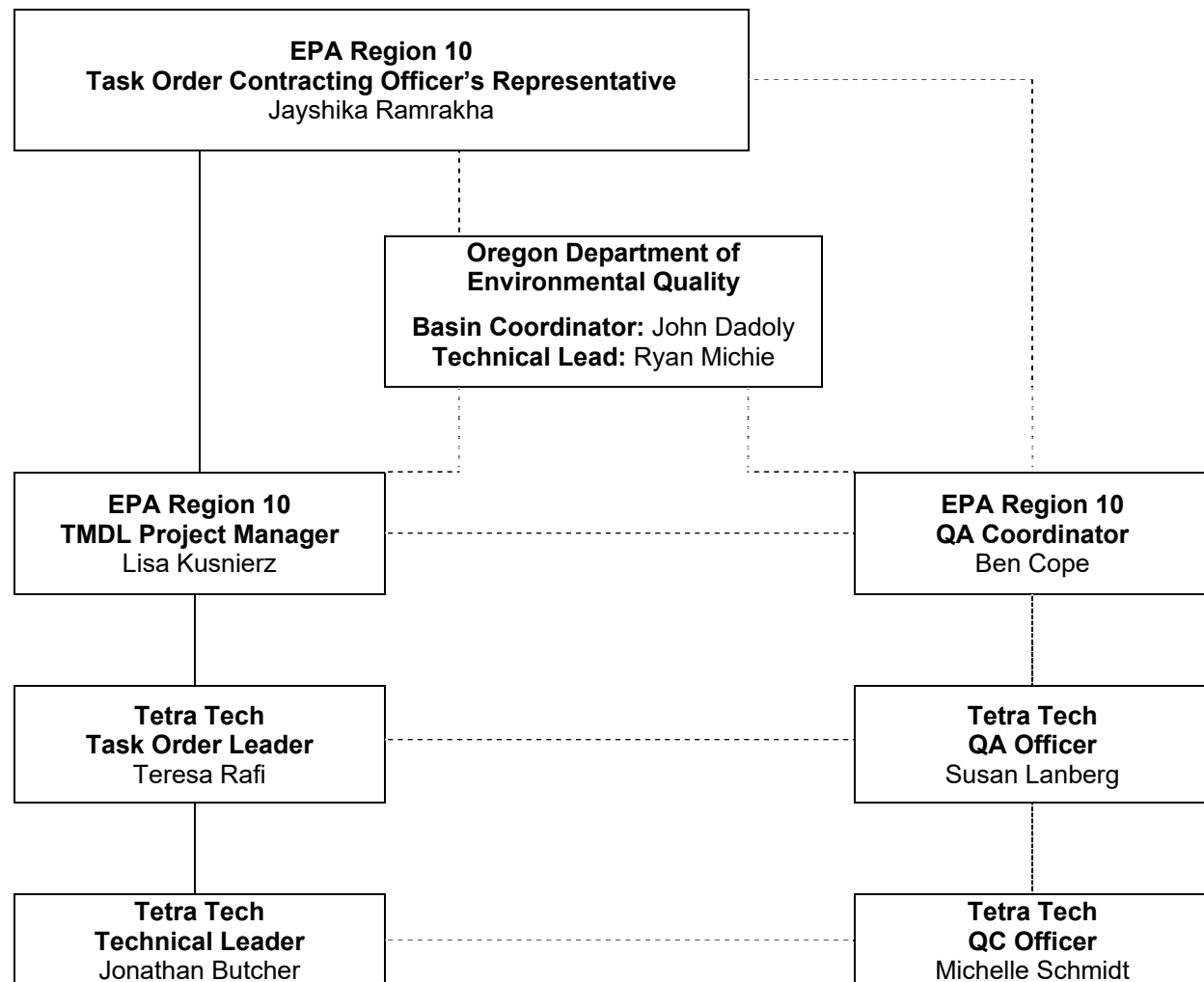


Figure I-1. Project Organization (dashed lines indicate communication only; solid lines indicate authority)

Table I-1. Key Personnel, Titles and Areas of Responsibility.

TITLE	DESCRIPTION OF DUTIES/RESPONSIBILITIES
EPA Region 10 Task Order Contracting Officer's Representative	Oversees the technical and administrative aspects of project performance. Issues all technical directives for work and reviews contract requirements prior to initiation of environmental data operations (data collection, management, and any subsequent analyses). Reviews and approves project work plans and quality documentation.
EPA Region 10 TMDL Project Manager	Responsible for overseeing project planning and ensures that all appropriate project work aligns with TMDL project objectives. Verifies effective implementation of the QAPP requirements at the project level within the scope of their activities. Reviews and approves project work plans and quality documentation.
EPA Region 10 QA Coordinator	The Region 10 QA Coordinator, Ben Cope, has delegated authority from the Region 10 QA Manager to oversee QA for all modeling projects. The QA Coordinator oversees the quality system development and implementation in accordance with EPA quality policy and contract requirements, as appropriate. Reviews and approves project work plans and quality documentation. Provides oversight for model code updates, data selection/gathering, model selection, model calibration, and adherence to project objectives. Authorized to stop work if work is performed contrary to or in the absence of prescribed controls.
Oregon DEQ Basin Coordinator	The Oregon DEQ Basin Coordinator, John Dadoly, is Oregon's coordinator for the Snake River and is responsible for review of the model QAPP and TMDL, developing Oregon's WQMP, convening and coordinating the TMDL advisory committee, participating and presenting at TMDL public meetings, and response to public comments.
Oregon DEQ Technical Lead	The Oregon DEQ technical lead, Ryan Michie, leads, oversees, and directs DEQ technical staff and is responsible for coordination with EPA and Tetra Tech on model QAPP development, model calibration and scenarios, interpretation of model results, TMDL document writing, and response to public comments.
Tetra Tech Task Order Leader	Oversees work performed by Tetra Tech to meet EPA project requirements. Supervises the assigned project personnel (engineers and support staff) in providing for their efficient utilization by directing their efforts either directly or indirectly on projects. Other specific responsibilities include: coordinate project assignments in establishing priorities and scheduling; ensure the completion of high-quality projects within established budgets and time schedules; provide guidance and technical advice to those assigned to projects by evaluating performance; implement corrective actions and provide professional development to staff; prepare and/or review preparation of project deliverables; and interact with clients, technical reviewers, and agencies to ensure technical quality requirements are met in accordance with contract specifications.
Tetra Tech QA Officer	Assists the Task Order Leader in the development of the project QAPP. Reviews and approves the QAPP. Performs general QA oversight for this project. Provides data verification and validation per the QAPP.
Tetra Tech Technical Leader	Leads and supervises model coding, model setup, data selection/gathering, model verification and calibration work, and is responsible for ensuring that work is carried out and documented in a manner that is consistent with the procedures and quality requirements specified in the QAPP. Reviews model setup and documentation for work conducted by others.
Tetra Tech QC Officer	A senior technical reviewer, the QC Officer reviews work products and documentation of work conducted by others and responsible for performing evaluations to ensure that QC is maintained throughout the data collection and analysis process. Remains a daily resource for technical, quality, and documentation guidance and direction.

SECTION II: PROBLEM DEFINITION AND MANAGEMENT OBJECTIVES

On October 4, 2019, U.S. EPA was issued a final order and judgment to replace 15 Oregon temperature TMDLs that cumulatively address over 700 temperature impaired segments. The TMDLs must be replaced over an eight-year period with the majority of technical work completed in the first two years starting January 2020 through December 2021. Oregon Department of Environmental Quality (ODEQ) is generally leading the effort to develop replacement TMDLs with contract and staff support from EPA but has asked EPA to be the technical lead for the TMDL for the Snake River - Hells Canyon, which contains portions of the Snake River located on the Oregon/Idaho border. To meet the court mandated schedule, the approach to complete these TMDLs will rely on previously completed technical work as much as possible with a streamlined development process. Under this approach, TMDL replacement documents will be organized in a standardized fashion with consistent tables and similar language where possible. Narrative content in the TMDLs will be brief and limited to the information needed to address the rule requirements. ODEQ has completed a call for data for all waterbodies affected by the litigation, including Snake River - Hells Canyon, and those data are all stored in the ODEQ AWQMS (Ambient Water Quality Monitoring System) database. There will be no new data collection.

Since the completion of the 2004 Snake River – Hells Canyon TMDL (ODEQ and IDEQ, 2004), Idaho Power Company (IPC) has updated its CE-QUAL-W2 model for temperature using the time period from calendar year 2014 through 2018. IPC is also currently funding Portland State University (PSU) and Reed Harris Environmental Ltd. to develop methylmercury simulation capability in this model to support a United States Geological Survey (USGS) study, so this model can also be used for development of a future mercury TMDL based on preliminary planning meetings. Based on these existing and pending modeling capabilities, EPA anticipates that this CE-QUAL-W2 model will be the basis for the assessment tool used for the new temperature TMDL. However, the listed segments of the Snake River extend both upstream and downstream of the Hells Canyon reservoir complex to include free-flowing segments of the river from the Idaho border near Adrian, OR (River Mile (RM) 409) to the state line between Oregon, Idaho, and Washington (RM 176) (Table II-1 and Figure II-1), which means the current geographic extent of the model does not align with the extent of the temperature impairments. The 2004 Snake River – Hells Canyon TMDL ended upstream of the Washington-Oregon border just above the confluence with the Salmon River (RM 188). Additionally, EPA used the RBM10 model as the basis for its 2020 temperature TMDL for the Columbia and Lower Snake Rivers, which has an upstream extent in the Snake River at its confluence with the Clearwater River near the state line between Idaho and Washington (RM 139), and the U.S. Army Corp of Engineers (USACE) has developed a CE-QUAL W2 model for the Lower Snake with an upstream extent at RM 148. Therefore, the model must be extended so the revised Snake River-Hells Canyon TMDL will at least include the impaired segments from RM 409 to RM 176. However, the model will also be extended farther downstream to RM 139 to overlap with the USACE model and bridge the gap to the upper extent of the 2020 Lower Snake TMDL. Since the Snake River – Hells Canyon TMDL project area as well as the gap between it and the Lower Snake TMDL is part of the contributing source area to the Lower Snake, extending the model downstream to RM 139 is anticipated to aid EPA Region 10 in future analyses and implementation of the Lower Snake TMDL.

Table II-1. Snake River Assessment Units Classified as Water Quality Limited (Category 5 or 4a) for Temperature based on Oregon's and Idaho's Section 303(d) 2018/2020 Integrated Reports

Assessment Unit Name	Assessment Unit ID
Oregon Category 5 Listings	
Hells Canyon Reservoir	OR_LK_1705020107_05_100582
Snake River - Hells Canyon Reservoir to Sheep Creek	OR_SR_1706010101_02_103274
Snake River - Sheep Creek to Getta Creek	OR_SR_1706010102_02_103280
Snake River - Getta Creek to Salmon River	OR_SR_1706010103_02_103282
Snake River - Salmon River to Stateline	OR_SR_1706010301_02_103306
Snake River - Boise River to Malheur River	OR_SR_1705011501_02_103231
Snake River - Malheur River to Mann Creek	OR_SR_1705011502_02_103230
Snake River - Hog Creek to Mann Creek	OR_SR_1705020101_02_103229
Snake River - Idaho to Boise River	OR_SR_1705010311_02_102702
Brownlee Reservoir	OR_LK_1705020103_05_100578
Brownlee Reservoir	OR_LK_1705020311_05_100605
Idaho Category 5 Listings	
Snake River – Salmon River to Cottonwood Creek	ID17060103SL004_08
Snake River (Asotin Cr to WA state line)	ID17060103SL001_08
Idaho Category 4a Listings	
Snake River - Boise River to Weiser River	ID17050115SW001_08
Brownlee Reservoir, Upper (Weiser to Porters Flat)	ID17050201SW004_08
Brownlee Reservoir, Lower (Porters Flat to Brownlee Dam)	ID17050201SW003_08
Oxbow Reservoir	ID17050201SW002_08
Hells Canyon Reservoir	ID17050201SW001_08
Snake River - Hells Canyon Dam to Sheep Creek	ID17060101SL003_08
Snake River - Sheep Creek to Wolf Creek	ID17060101SL002_08
Snake River - Wolf Creek to Salmon River	ID17060101SL001_08
Washington Category 4a Listing	
Snake River	WA170601030303_01_01

Note: Idaho category 4a segments with temperature impairments were shifted from category 5 to category 4a based on the 2004 TMDL (IDEQ and ODEQ, 2004). The Washington listing was placed in Category 4a based on the Columbia and Lower Snake River TMDL.

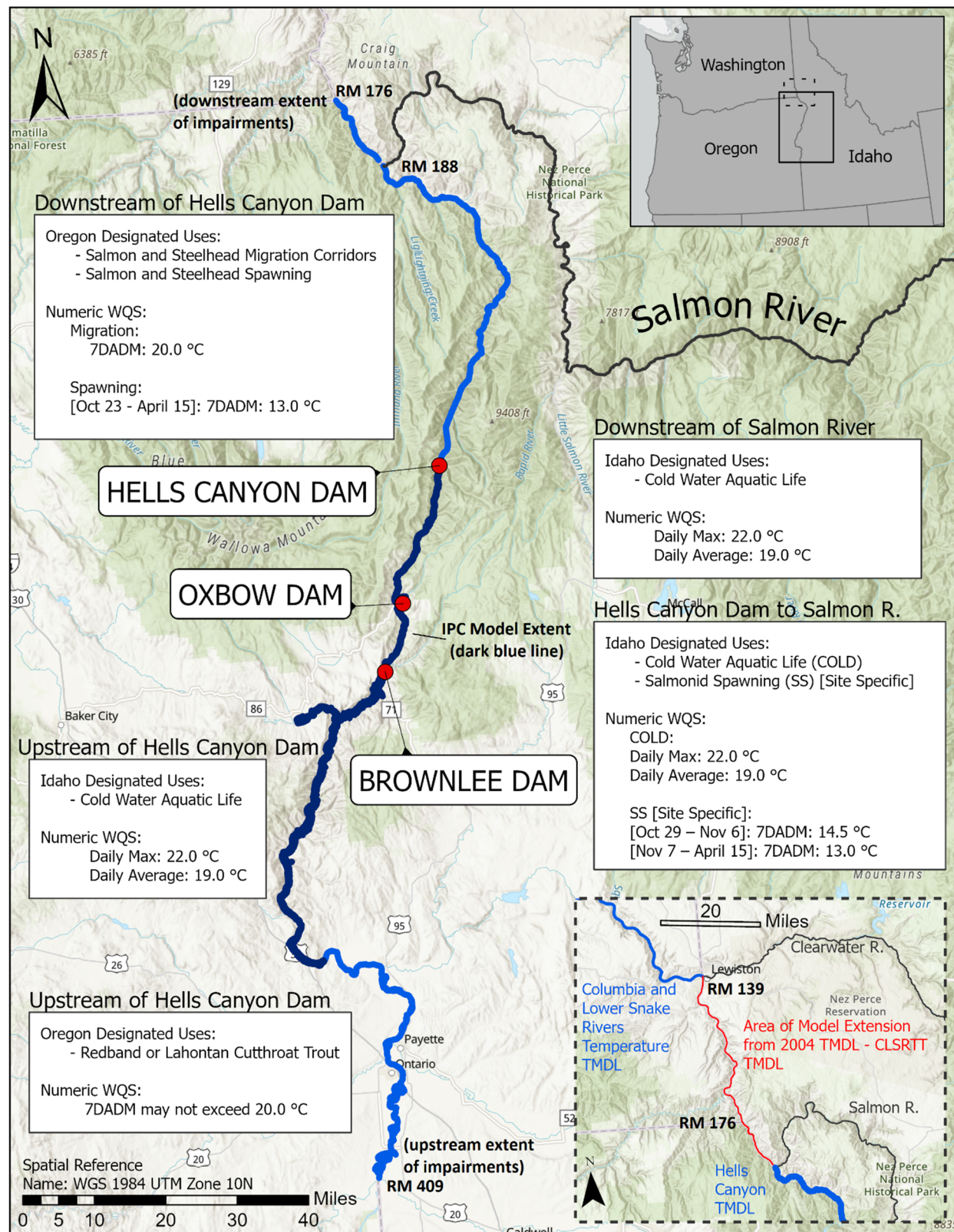


Figure II-1. Snake River - Hells Canyon TMDL Extent and Model Extent (inset)

The analysis and modeling work that is the subject of this QAPP is described in Task 4 and Task 5 of the technical directive issued under Task Order 001 of contract EP-C-17-046. The following subtasks are included in this project:

1. ***Project Administration and Kick Off Call.*** Tetra Tech will set up conference calls with the Team, which includes EPA staff and periodic attendance of ODEQ staff at key milestones (shown under “contacts information” below). The Kick-Off conference call will cover the background, scope, goals, schedule, and projected outcomes and outputs, as well as providing Tetra Tech with enough information to begin the tasks outlined in this technical direction. Tetra Tech will summarize the key points, outcomes and action items from each conference call and send it out to the Team.

There will be up to five conference calls held during Phase 1. The Task Order Contracting Officer Representative (TOCOR)’s role is to provide technical direction to Tetra Tech including directing Tetra Tech to address the project team’s comments or use a certain approach.

2. ***Model Review.*** EPA will obtain the current IPC model files and documentation, and Tetra Tech will review this information and identify any areas of missing information and/or potential model improvements based on TMDL project goals and needs. Findings and recommendations shall be summarized in a technical memorandum.
3. ***QAPP Development.*** Tetra Tech will develop a QAPP to document the modeling approach to be used for the Snake – River Hells Canyon temperature TMDL. The QAPP organization and content shall be consistent with EPA Region 10 modeling guidance (USEPA Region 10, 2016). Tetra Tech will use the Columbia River QAPP as a template to develop the QAPP for the Snake – River Hells Canyon Technical Work. The QAPP will discuss and identify model acceptance criteria for the revised modeling.
4. ***Model Extension and Refinement.*** With technical direction from the TOCOR, Tetra Tech will extend and refine the model to develop the capabilities necessary for the TMDL consistent with the QAPP. Subtasks include:
 - a. Extend the geographic boundaries of the existing model to align with the TMDL study area and available data for boundary condition inputs. The existing temperature model developed by PSU for IPC has been developed for the Hells Canyon Complex, which includes three reservoirs (Brownlee, Oxbow and Hells Canyon). The geographic scope of the TMDL is approximately from the Snake River mainstem at the Idaho border near Adrian, OR (RM 409) to the state line with Washington (RM 176), although the model will be extended to RM 139 near the state line between Idaho and Washington where the Snake River turns west. This includes the three Hells Canyon Complex reservoirs as well as riverine segments of the Snake River upstream and downstream of the reservoirs. Contractor will research and document available information (e.g., surveys, cross-sections, Light Detection and Ranging [LiDAR]) to characterize morphology of the channel in the extended areas upstream and downstream of the existing model boundaries.
 - b. Add any additional or excluded sources (e.g., point sources, small tributaries omitted from the existing model, tributaries to the model extension segments)

-
- to the newly extended model. Tributary inputs will be included but tributary watersheds are not part of the project. Tributary flows and temperature will be based on best available data, using flow gages where available and surrogate approaches (to be developed by Contractor) where not available.
- c. Test model performance and stability and adjust segmentation and time steps as needed: The extended model may include free-flowing segments with steep gradients, rapids, and potential super-critical flow. It may be challenging to maintain model stability and/or a workable model timestep for these reaches. Contractor will therefore undertake tests of model performance and stability and adjust model segment dimensions and timesteps to obtain a workable model.
 - d. Calibrate the model across the expanded geographic scope as needed. Tetra Tech will calibrate the model for flow and temperature in accordance with procedures agreed upon in the approved QAPP. Some refinements to model calibration may also be needed within the existing geographic scope of the model if identified under Task 2. Contractor will summarize model refinements in a model development report that addresses data quality control and evaluation of model acceptance criteria consistent with the QAPP organization and information for efficiency.
 - e. Respond to two rounds of review, first from EPA and second from ODEQ and IPC (and potentially other organizations involved in Hells Canyon activities such as USGS).
5. ***Model Scenarios.*** Tetra Tech will develop model scenarios to support TMDL development. The work under this task is anticipated to include development of the following:
- a. “Free-flowing” scenario where the three Hells Canyon Complex dams are mathematically removed, and free-flowing hydrodynamics and water quality conditions are simulated as well as restored riparian vegetative shading. This will require research and consultation to characterize geometry of the free-flowing channel. Both topographic and vegetative shading will need to be revised for the segments contained in the existing Hells Canyon Complex model, while restored vegetative shading will be represented in the additional model reaches upstream and downstream of the Hells Canyon Complex.
 - b. “Background” scenario with all known anthropogenic sources of thermal load removed. This scenario evaluates the stream temperature response from background sources only. Background sources include all sources of pollution or pollutants not originating from human activities. Background sources may also include anthropogenic sources of a pollutant that Oregon DEQ or another Oregon state agency does not have authority to regulate, such as pollutants emanating from another state, tribal lands, or sources otherwise beyond the jurisdiction of the state (OAR 340-042-0030(1)).
 - c. “Restored vegetation” scenario that evaluates the stream temperature response with streamside vegetation at restored conditions.
 - d. “No source” scenario with all known anthropogenic sources of thermal load removed. This includes removal of point sources, setting tributary temperatures to estimated natural temperatures, and “Free-Flowing” hydrodynamic conditions.
-

- e. “Tributary” scenario with “Current conditions” for all model inputs except for adjusted tributary temperatures. There are a variety of options for setting tributary mouth temperatures in a scenario. Alternatives include setting temperatures to applicable numeric temperature criteria for each tributary and/or adjusting temperatures by fixed increments to assess the impact of incremental changes in tributary mouth temperatures on mainstem Snake River temperatures. This latter approach would support evaluation of allocation of a fraction of the human use allowance to tributaries.
- f. “No point source” scenario with “Current Conditions” used for all model inputs except point sources, which are removed.
- g. “TMDL wasteload allocations” scenario with “Current Conditions” for all model inputs except point sources are set to the assigned wasteload allocation temperatures and flows.

In addition to the definition of technical tasks, subtasks, and deliverables, a schedule of deliverables is included in Table X-1 in Section X.D of this QAPP.

SECTION III: CONCEPTUAL MODEL: KEY PROCESSES AND VARIABLES

The existing PSU/IPC CE-QUAL-W2 model is a mathematical model of the water and thermal energy budgets of the mainstem Snake River in the vicinity of the Hells Canyon reservoir complex. CE-QUAL-W2 is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality model capable of predicting water surface, velocity, temperature, dissolved oxygen, algae, zooplankton, and numerous water quality constituents. The model is set up to predict these state variables at longitudinal segments and vertical layers.

Typical CE-QUAL-W2 longitudinal resolution is between 100-1000 m; vertical resolution is usually between 0.5 m and 2 m. The model can also be used in quasi-3-D mode, where embayments are treated as separate model branches off the main stem of the reservoir. The user manual and documentation (Wells, 2021a) can be found at: <http://www.cee.pdx.edu/w2>.

The CE-QUAL-W2 model of the Hells Canyon complex is being developed for IPC by PSU using model version 4.5. To date the model has been calibrated for flow and temperature and is documented in draft form (Wells et al., 2021b). The full water quality model being developed for the Hells Canyon Complex is planned to include many further updates including mercury cycling, atmospheric deposition, ammonia volatilization, and updates to the sediment diagenesis model (because it is intended to support ODEQ’s development of a methylmercury TMDL). Tetra Tech has received the model from PSU and has reviewed the draft model documentation and found it to be acceptable for use in this TMDL (see review included as Appendix 1). The CE-QUAL-W2 model calibration is near final; however, PSU has indicated that additional refinements of the model may be pursued. Any such refinements will be evaluated for inclusion in the TMDL model in consultation with EPA if received in a time frame consistent with completion of the TMDL.

The PSU/IPC CE-QUAL-W2 model of the Hells Canyon complex covers the three linked IPC reservoirs (in upstream to downstream order): Brownlee, Oxbow, and Hells Canyon (see Figure II-1). It does not include the free-flowing river reaches downstream of Hells Canyon Dam. The boundary between Brownlee Reservoir and the upstream free-flowing Snake River is variable,

depending on the reservoir water surface elevation. The model domain is extended upstream to RM 345.6 to include the extent of Brownlee at full pool but does not include the river reaches upstream of that point. The total mainstem length included in the PSU model is 95.9 miles (Hells Canyon Dam to upper extent of Brownlee pool).

The model is constructed at a high spatial resolution. Brownlee, which is the largest reservoir, is represented with 239 lateral segments in 7 branches, with a maximum of 102 layers (1 m resolution) and is divided into 5 separate water bodies that allow specification of different meteorological inputs to different portions of the reservoir. Oxbow has 53 lateral segments in 57 layers, while Hells Canyon has 112 lateral segments in 81 layers.

Representation of water temperature is an integral part of hydrodynamic calibration because water temperature and stratification are important controls on the movement of water. The heat balance includes inflow from and outflow to the Snake River mainstem, tributary inflows, input of solar radiation, heat exchange with the atmosphere, and heat exchange with the sediment. There are no external permitted point source discharges to the PSU/IPC CE-QUAL-W2 model. The model contains a detailed representation of topographic shading, which has important effects on solar radiation input. The model is calibrated to an extensive series of vertical profiles and outflow temperatures collected by IPC and runs for calendar years 2014-2018.

SECTION IV: TECHNICAL APPROACH

IV.A OVERVIEW

The existing CE-QUAL-W2 model of the Hells Canyon complex is believed to be adequately developed, calibrated, and documented for use in the TMDL. This was confirmed by Tetra Tech as part of the model review under Task 2 as documented in Appendix 1.

The geographic scope of the TMDL is approximately from the Snake River mainstem at the Idaho border near Adrian, OR (RM 409) to the state line with Washington (RM 176), although the model will be extended to the state line between Idaho and Washington at Lewis, ID just upstream of the confluence with the Clearwater River where the Snake River turns west (approximate RM 139). This model extension will require expanding the existing CE-QUAL-W2 model in both upstream and downstream directions. A separate version of the model(s) covering the Hells Canyon complex area will also be developed for a free-flowing scenario (without dams).

IV.B MODEL SELECTION

The work described in this QAPP does not involve the creation of new simulation modeling software or selection of modeling software. Rather, it involves the evaluation, update, and extension in space of an existing model, CE-QUAL-W2, that was developed by PSU/IPC expressly for the evaluation of water temperatures in the Snake River Hells Canyon complex. The quality of the model calibration for temperature is good (see Appendix 1), making it an appropriate tool for use in the temperature TMDL. The two-dimensional (longitudinal/vertical) configuration of the model is appropriate for the simulation of large, free-flowing rivers, and the same modeling framework used for the Hells Canyon Complex reservoirs will be applied to the extended free-flowing reaches of the study domain for consistency. In addition, CE-QUAL-W2 provides capabilities for the simulation of mercury which would make the model useful for a

potential future mercury TMDL application. (PSU is currently enhancing the capabilities of CE-QUAL-W2 for mercury simulation.)

IV.C SOFTWARE DEVELOPMENT QUALITY ASSESSMENT

CE-QUAL-W2 is an established and well-documented public domain model. New software development is not anticipated for this project. If any such development is required, the QC officer (or designee) will conduct surveillance on software development activities to ensure that all tasks are carried out in accordance with the QAPP and satisfy user requirements.

SECTION V: MODEL DEVELOPMENT

V.A MODEL BOUNDARIES

The extended CE-QUAL-W2 model will cover the Snake River mainstem from the Idaho border near Adrian, OR (RM 409) to the state line between Idaho and Washington just upstream of the confluence with the Clearwater River at Lewiston, ID (approximately RM 139). Major tributaries (Table V-1) to this portion of the Snake River are treated as inputs to the main stem river. The extended model will contain the five tributaries already incorporated into the Hells Canyon complex model, five major upstream tributaries, and three downstream tributaries. Methods for estimating flows from these tributaries based on available gage records are discussed in ODEQ and IDEQ (2004) and Wells et al. (2021b) and will be followed in the new work. Minor tributary inputs will be treated as distributed sources.

Table V-1. Major Tributary Sources in the Extended CE-QUAL-W2 Model

Within existing Hells Canyon Complex Model	Upstream of Brownlee Reservoir	Downstream of Hells Canyon Reservoir
Burnt River	Owyhee River	Imnaha River
Powder River	Boise River	Salmon River
Daily Creek	Malheur River	Grande Ronde River
Wildhorse River	Payette River	
Pine Creek	Weiser River	

V.B SPATIAL AND TEMPORAL RESOLUTION

The model simulation period will be the same as in the existing CE-QUAL-W2 model of the Hells Canyon complex, covering calendar years 2014-2018. There will not be a separate model validation or corroboration period.

Spatial resolution for the models that cover the Hells Canyon complex will not be modified. For the unimpounded, free-flowing sections of the Snake River within the model domain the spatial length scales of the model will be determined by a number of factors. These factors include the availability of geometric data, spatial variability in the river geometry, and computational stability and accuracy. Sufficient data on river geometry appear to be available to develop a high-resolution representation of the channel as described in Section V.D.1. Use of large longitudinal segments degrades accuracy in the model solution. CE-QUAL-W2 has an adaptive timestep; however, use of smaller model segments requires shorter timesteps, which can result in very long run times. This is especially true for fast-flowing rivers and velocities at the entrance to Brownlee Reservoir, which are reported to be in the range of 1 m/s during high flow events

(Wells et al., 2012b). Because CE-QUAL-W2 has many adjustments to improve model stability in river simulations, it is not possible to a priori predict the required time step for a given resolution. It is anticipated that significant experimentation will be needed to determine a reasonable trade-off between grid resolution, model accuracy, and model stability.

V.C SOURCE CHARACTERISTICS

External sources of thermal load to the Snake River mainstem in the TMDL reaches are predominantly meteorological inputs and tributary inflows, which contain a mix of both natural and anthropogenic loading. There are several permitted point sources that discharge directly to the TMDL segments of the Snake River upstream of Brownlee Reservoir. These are summarized in Section V.D.6. The temperature of the Snake River is also directly influenced by the release and management of water impounded by the Hells Canyon complex of dams.

When available, daily measured flows and water temperatures will be used for the model input conditions; however, daily water temperatures are not available or infrequently measured for all of the tributary sources. Data availability is discussed below in Section V.D.

V.D DATA AVAILABILITY AND QUALITY

Nondirect measurements (also referred to as secondary data) are data previously collected under an effort outside this contract that are used for model development and calibration. Other secondary data will be assembled from other sources. Table V-2 lists the secondary sources that Tetra Tech will evaluate for use in model setup and/or calibration. The sections below provide details regarding how such secondary data will be identified, acquired, and used for this task.

Table V-2. Sources of Key Secondary Data

Data Type	Source
River geometry	Bathymetry data and HEC input files provided by IPC and U.S. Army Corps of Engineers
Tributary and mainstem flow	U.S. Geological Survey gaging (National Water Information System)
Meteorology	National Climatological Data Center Surface Airways Meteorological and Solar Observing Network (SAMSON) data, local climatological data (LCD); U.S. Bureau of Reclamation AgriMet data;
Tributary and mainstem water quality	U.S. Geological Survey, Washington Department of Ecology, Oregon Department of Environmental Quality, Idaho Power Company data, U.S. Bureau of Reclamation

V.D.1 River Geometry

Adequate information on channel geometry is essential to building a CE-QUAL-W2 model. Detailed geometry is already established for the Hells Canyon complex (Wells et al., 2021b), but was needed for the free-flowing reaches where the model is being extended.

IPC provided bathymetry data for reaches upstream and downstream of the Hells Canyon complex in HEC-RAS geometry and geographical information system (GIS) shapefiles. The shapefiles are exports of the HEC-RAS geometry files and georeferenced. The upstream cross section covers the Snake River between the head of Brownlee Reservoir and RM 399 near Adrian, OR (Figure V-1(a)). These data were collected by Ayres Associates in June 1997 and April 1999 using a sonic depth sounder that was linked to a survey-grade, real-time kinematic

geographic positioning system (GPS) data. River geometry will need to be extended upstream to RM 409. This will be approximated based on aerial imagery (for width), the DEM (for grade), and assumptions that the channel shape and width-to-depth ratio is similar to that reported for RM 395-399.

The downstream cross sections provided by IPC cover from Hells Canyon Dam to the Washington State line and were developed using 2017 bathymetric data and topographic data from USACE LiDAR collected in 2010 (Figure V-1(b)).

For the Snake River from the Oregon-Washington state line to the confluence with the Clearwater River USACE has developed a HEC-RAS model. EPA provided a copy of “Section 3 Snake River Model Development.pdf” which was developed as an appendix to the unpublished draft Columbia River System Operations Environmental Impact Statement and describes the USACE HEC-RAS model. Section 3.1.2.3.1 states that “The model extends from the Lower Granite pool at river mile 106.87 to 178.27, representing 71.4 miles of the Snake River.” The accompanying table 6 states that Snake River RM “138.37 to 178.27” has 175 cross sections at an average spacing of 1,263 feet. Tetra Tech has a copy of the USACE HEC-RAS model of the Snake River obtained in a previous project on the Columbia River system. This contains a river Thalweg line that extends to approximately RM 178 and the listing of cross sections and average spacing is consistent with a distance of 40 miles; however, the geometry files provided to Tetra Tech do not go upstream of RM 147.8. This suggests that cross sections between RM 148 and 178 have been removed from the model. To remedy this, Tetra Tech will first see if the missing cross sections can be obtained from USACE. If this is not possible, representation of this section of the river (which flows through a steep canyon in rugged mostly unpopulated terrain) will be represented by a generic cross section shape consistent with the channel characteristics just upstream of the Washington-Oregon border provided by IPC.

The vertical datum for the upstream cross sections is North American Vertical Datum of 1988 [NAVD88] (Geoid 3) and for the downstream cross sections the measurements are NAVD88 ellipsoid heights. The vertical datums for all cross sections need to be converted to National Geodetic Vertical Datum of 1929 [NGVD29] datum to be consistent with the existing Hells Canyon complex CE-QUAL-W2 model. CORPSCON v.6 software developed by U.S. Army Corps of Engineer ([Army Geospatial Center > What we do > Corpscon](#)) and previously used by IPC for conversion of vertical datum for the same data will be used for this task. The model segments and bathymetry file for the Hells Canyon complex were provided by PSU in Surfer format. These have been converted to GIS shapefiles and will be used to ensure a smooth transition between the Hells Canyon complex and the extended model section.

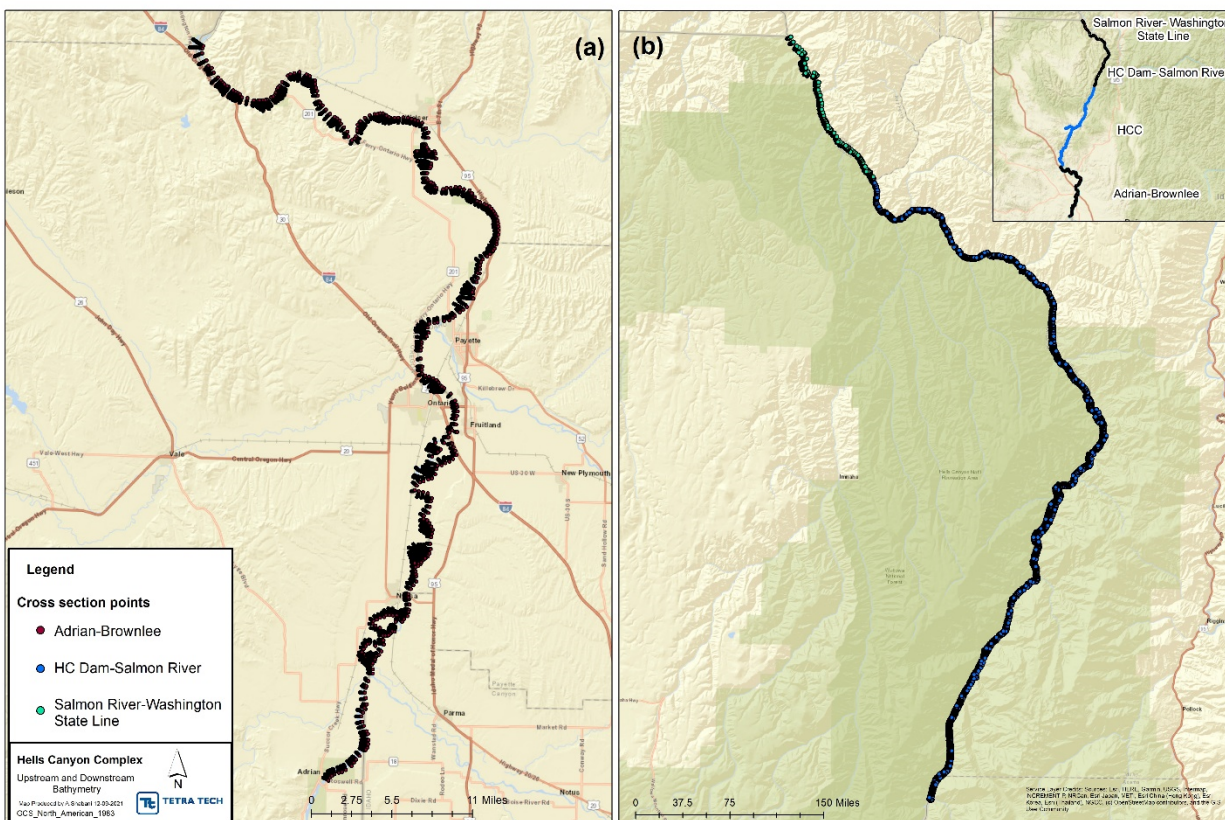


Figure V-1. Channel Cross Sections; (a) from Upstream of Adrian to Head of Brownlee Reservoir; (b) from Hells Canyon Dam to Oregon-Washington State line

V.D.2 Flow Data

Continuous flow gaging is needed for model development and calibration. Available gage data for the free-flowing reaches of the mainstem are summarized in Table V-3.

Table V-3. Flow Gaging for Snake River Free-flowing Mainstem Segments during Model Application Period

Gage Number	Location	Period of Record
USGS 13173600	SNAKE RIVER nr ADRIAN OR	2009-2010
USGS 13213100	SNAKE RIVER AT NYSSA OR	1974-present
USGS 13269000	SNAKE RIVER AT WEISER ID	1910-present
USGS 13290450	SNAKE RIVER AT HELLS CANYON DAM ID-OR STATE LINE	1965-present
IPC 9960	SNAKE RIVER BELOW HELLS CANYON DAM	1968-present
IPC 9820	SNAKE RIVER AT JOHNSON BAR, OR	1992-present
USGS 13317660	SNAKE RIVER AT MCDUFF RAPIDS AT CHINA GARDEN ID	2003-present
USGS 13334300	SNAKE RIVER NEAR ANATONE, WA	1958-present

The upstream boundary of the model approximately coincides with USGS gage 13173600 (Snake River near Adrian, OR). Flow records are available at this gage for only one water year. Therefore, the headwater flow for the model will need to be back-calculated either from the upstream gage Snake River near Murphy, ID (USGS 13172500) and/or from gage records at Nyssa, OR (USGS 1321300) after subtracting the contributions from the Owyhee River and Boise River and minor small streams that enter the Snake River between Adrian and Nyssa. The brief gage record at Adrian will allow testing of these calculations.

The model calibration report for the Hells Canyon complex (Wells et al., 2021b) contains a detailed assessment of the flow and water temperature records for the direct tributaries to the three reservoirs. Tetra Tech will review the specified time series but anticipates that they are acceptable for continued use in the model.

For major tributaries to the free-flowing reaches that are not in the existing Hells Canyon Complex model (Table V-1), the availability of gage data for flow down to the Washington-Oregon state line is summarized in ODEQ and IDEQ (2004) and was confirmed and updated for this QAPP. Two additional downstream tributaries within the expanded extent of the model (Grande Ronde River and Salmon River) also have USGS gages.

For the Imnaha River, USGS gage 13292000, Imnaha River at Imnaha, OR, ceased operation in 2013. Later flows for this relatively small tributary will be developed based on correlation of historic flows to nearby gages. Note that we propose to not individually represent small tributaries that contribute less than 1% to the flow in the Snake River, even if gage records are available (e.g., Asotin Creek, USGS gage 13335050). Instead, these may be represented as diffuse incremental inflows, if necessary, to preserve the water balance.

Two other special cases are the Owyhee River and Malheur River, where the available USGS gaging is upstream of the confluences with the Snake River. The U.S. Bureau of Reclamation (USBR) has developed a method for estimating total flow into the Snake from the Owyhee River and that method will be investigated for application to the current work (USBR, 2001). Flow in the Malheur River at 36th Street Bridge in Ontario, OR near the confluence with the Snake is available online from the Bureau of Reclamation Hydromet system (<https://www.usbr.gov/pn-bin/inventory.pl?site=MALO&ui=true&interval=daily>).

Sources of tributary flows during the model application period are summarized in Table V-4.

Table V-4. Sources of Tributary Flow Records

Tributary	Flow Data Source
Owyhee River	Idaho Power gage 13184005, Owyhee River near Adrian, OR (https://idastream.idahopower.com/)
Boise River	USGS gage 13213000
Malheur River	Bureau of Reclamation gage MALO
Payette River	USGS gage 13251000
Weiser River	USGS gage 13266000
Burnt River	Existing Hells Canyon Complex CE-QUAL-W2 model
Powder River	Existing Hells Canyon Complex CE-QUAL-W2 model
Daly Creek	Existing Hells Canyon Complex CE-QUAL-W2 model
Wildhorse River	Existing Hells Canyon Complex CE-QUAL-W2 model
Pine Creek	Existing Hells Canyon Complex CE-QUAL-W2 model
Imnaha River	Correlation analysis based on USGS gage 13292000
Salmon River	USGS gage 13317000
Grande Ronde River	USGS gage 13333000

V.D.3 Diversions

Water diversions directly from the Snake River within the proposed model extent do not appear to be a major issue at this time, although further research is needed. There are significant surface water diversions for agricultural uses within the Snake River Plain upstream of Brownlee; however, a preliminary review of water rights data from Idaho and Oregon suggests that these are primarily on tributaries to the Snake River, with only a few smaller diversions drawing directly from the Snake. Diversions from the tributaries upstream of gage points are implicitly accounted for in flow and water temperature records from those tributaries. A quick review of materials on the web suggests that diversions directly from the mainstem within the TMDL area are not a significant issue. In the area of the TMDL reaches upstream of Brownlee it appears that most irrigation water is supplied from the tributaries (Payette, Malheur, etc.) or groundwater and not from the mainstem Snake. The Hells Canyon Complex dams are used for hydropower only, and there is little agriculture present in the rugged terrain between Hells Canyon Dam and Clearwater River.

It does appear that there are water supply diversions from the Snake River to the cities of Ontario and Nyssa, OR that will require further investigation and evaluation for potential inclusion in the model. Tetra Tech will work with water resources agencies in Idaho, Oregon, and Washington to determine if there are other diversions direct from the Snake River that are of sufficient size to affect the water and heat balances in the river.

V.D.4 Meteorology

Meteorological data, including air temperature, dew point temperature, wind speed and direction, and cloud cover must be included in the meteorological file for CE-QUAL-W2. If available, short wave solar radiation can be input directly into the model.

Weather data have already been prepared for the Hells Canyon complex portion of the model domain (Wells et al., 2021b) and will be retained for the extended modeling effort based on the success of the temperature calibration. Due to limited direct monitoring and the extreme topography and large elevation change in this area, the meteorological input was developed primarily from a run of the WRF-NAM regional weather model, coupled with monitoring from Brownlee Dam.

In contrast to the complex thermal dynamics of the reservoirs, air temperature and solar radiation are the dominant meteorological factors that affect temperature in the free-flowing reaches.

The USBR maintains a network of agricultural weather stations called AgriMet stations ([AgriMet General Information | Bureau of Reclamation \(usbr.gov\)](https://www.usbr.gov/agrimet/)). These stations provide all the required meteorological inputs, including solar radiation, with the exception of cloud cover. We will use AgriMet data for Ontario, OR (43.97777 N, -117.01527W) and Parma, ID (43.80000 N, -116.93333 W) for the extended portion of the watershed upstream of Brownlee Reservoir. We will use the PRISM (Parameter elevation Regression on Independent Slopes Model; [Daly et al., 2008, 2015]) datasets for maximum and minimum air temperatures to interpolate between these points (<https://prism.oregonstate.edu/>). The PRISM products use a weighted regression scheme to account for complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other factors. Day time cloud cover will be back-calculated from incident solar radiation data and interpolated over the night.

No AgriMet stations or first order weather stations are available for the portion of the Snake River downstream of Hells Canyon Dam. For this section of the river, we will obtain precipitation, air temperature, and dew point estimates directly from PRISM. Other meteorological data will be obtained from the NLDAS-2 gridded product. NLDAS-2 (North American Land Data Assimilation System; Mitchell et al., 2004) provides hourly gridded meteorological data from 1979 to present at a 1/8-degree resolution. Output includes air temperature, specific humidity, surface pressure, solar radiation (downward longwave and shortwave radiation), and U and V wind components.

For the downstream end of the model, we will also investigate using data from Lewiston Nez Perce Co Airport, ID (72783024149) and AgriMet data from the Silcott Island station, located west of Clarkston, WA along the Snake River.

Shading is an important modulating factor on shortwave solar inputs and longwave thermal exchanges. For larger rivers in mountainous areas topography is the most important source of shading. Topographic shading depends on topography, aspect, and seasonal solar azimuth. The Hells Canyon section of the Snake River will be influenced by topographic shading as it is in steep terrain and flows south to north. Topographic and riparian vegetation shading will be accounted for in the calibration configuration for the added stream segments (shade is already incorporated in the existing model for the Hells Canyon complex).

To evaluate shading we will use Washington Ecology's Shade model and the accompanying ArcGIS TTools plug in (Kasper and Boyd, 2001; both at <https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs>). TTools can be used to sample stream width, aspect, topographic shade angles, and elevation for incorporation into the Shade model. The Shade model can then be used to quantify the potential daily solar load and generate the percent effective shade along the river corridor. The primary input data for the topographic shading analysis is a digital elevation model, for which we will use the USGS National Elevation Dataset (<https://gdg.sc.egov.usda.gov/Catalog/ProductDescription/NED.html>.)

As part of the shade analysis, Tetra Tech will identify the sensitivity of Snake River temperature responses to the inclusion of vegetative shading. This will provide information to help determine whether a full analysis of vegetative shading is needed for various management scenarios.

V.D.5 Water Temperature Observations

Continuous temperature data for the Snake River mainstem are needed to calibrate the model. Data for the Hells Canyon complex reservoirs have already been compiled (Wells et al., 2021b). For the free-flowing reaches within the TMDL domain, continuous USGS temperature gaging is available at two stations within the model domain downstream of Hells Canyon Dam and two stations upstream of Brownlee Reservoir (Table V-5). In addition, IPC has collected continuous water temperature data at numerous stations on the Snake River from 2009-2019 that are included in the Oregon DEQ online monitoring data system, including Snake RMs 189, 192.3, 202.3, 216.3, 229.8, 247.6, 269.8, 283.9, 345.2, 345.6, 354.3 and 383.

Table V-5. USGS Continuous Temperature Monitoring for the Free-flowing Snake River Segments for Model Application Period

Station	Name	Period of Record
Upstream of Hells Canyon Complex		
13173600	Snake River near Adrian, OR	2009-2010
13213100	Snake River at Nyssa, OR	1989-2015
13269000	Snake River at Weiser, ID	1972-2015
Downstream of Hells Canyon Dam		
13317660	Snake River at McDuff Rapids at China Garden, ID	2005-2021
13334300	Snake River near Anatone, WA	1959-2022

As with flow, continuous temperature records at the upstream boundary of the model area (RM 409) have not been identified with the exception of one year of data for Snake River near Adrian. If such records are not located, the upstream boundary temperature will need to be estimated from regression relationships to other stations (to be determined) as described below for filling missing tributary temperature data.

In contrast to the mainstem, many of the major tributaries to the free-flowing sections of the Snake River within the TMDL study area have gaps in temperature measurements during the model run period. Of the eight added tributaries listed in Table V-1, continuous temperature records during the 2014-2018 simulation period are available from USGS for the Boise River near Parma, ID (13213000), Payette River near Payette (13251000), Weiser River near Weiser

(13266000), and Salmon River at White Bird, ID (13317000). These can be used to establish boundary conditions. For the Malheur River, temperatures are monitored by the USBR at the 36th Street Bridge in Ontario, OR, about a mile upstream of the confluence with the Snake (station MALO). The historic records for temperature at this station do not seem to be available online but can likely be obtained from the USBR Columbia – Pacific Northwest Region office.

For each of the remaining tributaries as well as for the Snake River upstream of Weiser there are partial or complete gaps during the TMDL simulation period. For these tributaries, gaps in observed temperature series will be filled by establishing linear regression relationships to monitoring data at nearby tributaries with similar watershed characteristics. These relationships may be based on contemporaneous data during the TMDL simulation period or from earlier monitoring as appropriate. For instance, for the Grande Ronde River there is not a USGS temperature gage, but detailed temperature data were collected in 1999-2000 by Oregon DEQ in support of the Grande Ronde temperature TMDL and additional data were collected in 2019 by the Bureau of Land Management.

A summary of the methods proposed for specifying tributary temperatures for all the major tributaries is provided in Table V-6. Earlier continuous temperature time series that can be used to augment regression relationships to fill gaps are summarized in Table V-7.

Table V-6. Methods for Specifying Tributary Water Temperature

Tributary	Method
Owyhee River	Idaho Power temperature data at RM 3.2 2008-2018 in Oregon AWQMS, supplemented with regression based on USGS gage 13184000
Boise River	USGS gage 13213000
Malheur River	USBR gage MALO
Payette River	USGS gage 13251000
Weiser River	USGS gage 13266000
Burnt River	Existing Hells Canyon Complex CE-QUAL-W2 model
Powder River	Existing Hells Canyon Complex CE-QUAL-W2 model
Daly Creek	Existing Hells Canyon Complex CE-QUAL-W2 model
Wildhorse River	Existing Hells Canyon Complex CE-QUAL-W2 model
Pine Creek	Existing Hells Canyon Complex CE-QUAL-W2 model
Imnaha River	Idaho Power temperature data at RM 0.1 and 0.3 in Oregon AWQMS system
Salmon River	USGS gage 13317000
Grande Ronde River	Bureau of Land Management Station 61157 (2019 data only), provided by R. Michie, ODEQ) supplemented with regression analysis.

Table V-7. Earlier USGS and Oregon DEQ Continuous Temperature Monitoring for Estimating Tributary Temperature Regression Relationships

Station	Name	Period of Record
13172500	Snake River near Murphy, ID (upstream)	1997-2004
13292000	Imnaha River at Imnaha, OR	1965-1977
13184000	Owyhee River at Owyhee, OR	1979-1982
Various	Oregon DEQ Grande Ronde Temperature TMDL	1999-2000

V.D.6 Point Source Discharges

Point source discharges to the TMDL segments are summarized in ODEQ and IDEQ (2004, Table 2.5.0), and are recapitulated in Table V- (with one addition). These point sources are believed to have only minor impacts on the heat balance in the Snake River but will be evaluated for inclusion in the model based on Discharge Monitoring Reports. Point sources discharging to tributaries will be accounted for implicitly in tributary measurements or estimates of flow and temperature.

Table V-7. Permitted point sources discharging directly to the Snake River within the Snake River - Hells Canyon TMDL reach (RM 409 to 139).

Point Source	NPDES Permit Number	Location (RM)	Treatment Type	Current Design-flow (MGD)
City of Nyssa	101943 OR0022411	385	Activated sludge	0.8
Amalgamated Sugar	101174 OR2002526	385	Seepage ponds	Seepage
City of Fruitland	ID0020907	373	Facultative lagoon	0.5
Heinz Frozen Foods	63810 OR0002402	370	Activated sludge	3.4
City of Ontario	63631 OR0020621	369	Facultative lagoon	3.1
City of Weiser (WWTP)	ID0020290	352	Activated sludge	2.4
City of Weiser (WTP)	ID0001155	352	Settling pond	0.5 MGD (max) 0.09 MGD (avg)
Brownlee Dam (IPC)	ID0020907	285	See note 1	15
Oxbow Dam (IPC)	101275 OR0027286	272.5	See note 1	11
Hells Canyon Dam (IPC)	101287 OR0027278	247	See note 1	1
Asotin Sewage Treatment Plant	WA0020818	145	Activated sludge	0.164 (max monthly)

1. Facilities sump discharge and turbine cooling water, not a waste treatment source.

NPDES = National Pollution Discharge Elimination System; MGD = Million Gallons per Day; WTP = Water Treatment Plant; WWTP = Wastewater Treatment Plant

V.D.7 Quality Control for Nondirect Measurements

The majority of the nondirect measurements will be obtained from quality assured sources.

Tetra Tech expects that project specific QAPPs or similar documentation describing the performance criteria evaluated and met will be available for federal (USACE, National Oceanic

and Atmospheric Administration, USGS, USBR) and state sources. If such criteria are not reported for the parameters of interest in the documents or databases, Tetra Tech will determine how much effort should be made to find reports or metadata that might contain that information. Tetra Tech will perform general quality checks on the transfer of data from any source databases to another database, spreadsheet, or document.

The ODEQ water quality database currently contains temperature records provided by IPC. We will check with ODEQ to confirm that Oregon reviewed IPC's QA procedures before incorporating these data.

Where data are obtained from sources lacking an associated quality report, Tetra Tech will evaluate data quality of such secondary data before using it. Additional methods that might be used to determine the quality of secondary data are

- Verifying values and extracting statements of data quality from the raw data, metadata, or original final report
- Comparing data to a checklist of required factors (e.g., analyzed by an approved laboratory, used a specific method, met specified data quality objectives, validated)

If it is determined that such searches are not necessary or that no quality requirements exist or can be established, but the data must be used in the task, Tetra Tech will add a disclaimer to the deliverable indicating that the quality of the secondary data is unknown.

V.E TIME FRAME OF SIMULATION

The extended CE-QUAL-W2 model will cover the same time period as the model already developed for the Hells Canyon complex. This consists of calendar years 2014-2018.

V.F IMPORTANT ASSUMPTIONS

Key assumptions made during the collection, handling, transformation (harmonizing format and terms for compilation), and incorporation of data into the existing model will be discussed with the TOCOR, as appropriate, and will be documented in the draft and final technical memorandum, and/or model files.

V.G MODEL CALIBRATION

Calibration tunes the model to represent conditions appropriate to the waterbody and watershed under study. A robust simulation of water quality requires an accurate representation of hydrology. The model will be calibrated through a sequential process, beginning with the flow balance and hydrology, followed by water temperature. A description of the model calibration process will be included in the Model Development Report.

Tetra Tech will undertake calibration for the free-flowing reaches not simulated in the Hells Canyon Complex model using the mainstem gage records summarized in Table V-3. It is anticipated that the parameters currently assigned to the CE-QUAL-W2 model of the Hells Canyon Complex will not change unless PSU issues an update to the model calibration, which is currently in draft form (Wells et al., 2021b). New calibration will be required for the free-flowing model reaches of the extended model (the lighter blue line in Figure II-1).

The primary calibration targets for hydrology in the free-flowing reaches will be gaged flow and stage. These will be supplemented by velocity measurements obtained by USGS during rating curve evaluation. Both the overall water balance and flow velocities are important to the temperature simulation.

The temperature simulation will endeavor to replicate recorded water temperature at each mainstem site shown in Table V-5.

V.H MODEL PARAMETERS

This section pertains to default model parameters and those which will be most likely manipulated to improve model/measurement fit. For the Snake River - Hells Canyon model extension, we intend to keep the parameter values used in the Hells Canyon complex calibrated model and will rely on CE-QUAL-W2 guidance and documentation for initial values of other heat-related parameters.

The accuracy of a heat balance model depends in large part on the uncertainty in the segmentation, flow simulation, channel morphology, and external boundary conditions (tributaries, headwaters, and meteorology). It may be challenging to obtain a stable flow simulation at a feasible time step due to the high gradient in parts of the system and we may need to experiment with different segmentation options. It is likely, as suggested in the CE-QUAL-W2 manual, that it will be necessary to break the free-flowing segments into several different, independent but linked waterbodies that differentiate areas with different average slopes and weather data. This also can help resolve problems where portions of a steeply sloped channel are simulated as going dry during the simulation.

Sufficient cross-section data are available to parameterize river geometry for most of the model reaches, but some assumptions may need to be made, particularly for RM 148 to 178 and 399 to 408 (as described in Section V.D.1). The key adjustment for matching observed flows and water depths is anticipated to be the friction factor. The Hells Canyon complex model (Wells et al., 2021b) already contains the results of experiments with the friction factor for the flowing reach at the upstream end of Brownlee Reservoir that provides a good starting place for this parameter. Flow and hydrodynamics will also be assessed and improved as needed by reviewing data inputs and ensuring that channel slopes, widths, and depths are correct, resulting in appropriate velocities and flows within the channel.

Many of the parameters controlling heat exchange within flowing reaches have specified default values that are usually left unchanged. Uncertainty in the meteorological forcing and tributary inputs is usually more significant and may require iterative adjustments. A wind sheltering factor that adjusts estimated wind to actual conditions at the water surface is often a key calibration factor. Other parameters impacting temperature will be adjusted, including rate of heat transfer due to evaporation, and parameter adjustments will be made in accordance with recommended rates and constants found in the CE-QUAL-W2 model documentation.

SECTION VI: MODEL EVALUATION AND ACCEPTANCE

VI.A MODEL UNCERTAINTY AND SENSITIVITY

The primary purpose of the extended CE-QUAL-W2 model will be to assess the importance of different heat input contributions to water temperature excursions of the applicable water quality

criteria in the Snake River – Hells Canyon TMDL project area. The model must also reasonably predict the response of water temperature in the Snake River to changes in weather, upstream boundary inputs, tributary inputs, and operation management. An important input to any decision-making process is information on the degree of uncertainty that is associated with model predictions.

As with any mathematical approximation of reality, a water quality model is subject to significant uncertainties. Direct information on the aggregate prediction uncertainty will arise from the model calibration exercise; however, further diagnostics are needed to understand the sources and implications of uncertainty.

The major potential sources of model uncertainty include the mathematical formulation, boundary conditions data uncertainty, calibration data uncertainty, and parameter specification. In many cases, a significant amount of the overall prediction uncertainty is due to boundary conditions (e.g., uncertainty in estimation of ungaged tributary flows and temperature) and uncertainty in the observed data used for calibration and validation. These sources of uncertainty are largely unavoidable, but do not invalidate the use of the model. Uncertainties in the mathematical formulation and model parameters are usually of greater concern for decision purposes because these formulations may significantly affect the cause and effect relationships predicted by the model.

The CE-QUAL-W2 model has a long history of application as a public-domain model and has been extensively evaluated to determine uncertainty in the model equations. In addition, successful application to replicate observed water temperatures in the Hells Canyon Complex confirms the model's ability to represent water temperatures in the system with a high level of accuracy. It is not anticipated that additional uncertainty or sensitivity analyses will be performed on the existing calibrated model.

For the extended free-flowing portions of the model, Tetra Tech will perform calibration and report statistical analyses of model fit including average error, average absolute error, root mean squared error, and the Nash-Sutcliffe model efficiency coefficient. These measures will help to characterize the uncertainty in model outputs. In addition, Tetra Tech will undertake targeted sensitivity analyses to evaluate how model predictions and model uncertainty respond to specification of model parameters and perturbations in external boundary conditions including tributary flow and water temperature, as well as uncertainty in the estimation of meteorological inputs.

VI.B MODEL ACCEPTANCE

For a model to be utilized in the development of TMDLs, National Pollutant Discharge Elimination System permits, or other water program decision, the model must first be accepted by the regulatory agencies and stakeholders. The most common model development goals are (1) to minimize the difference between simulated and observed water quality and (2) to capture the spatial and temporal patterns in the observed water quality conditions. Progress toward achieving these goals is commonly captured in error statistics and graphical plots. However, model quality goes beyond these core evaluations. Several parallel tasks to achieve overall model quality are pursued alongside efforts to reduce model error, including:

- 1) Incorporation of all available observations of the system (e.g., geometry, flow, boundary inputs/withdrawals, meteorology) meeting QA/QC requirements for the time period simulated.
- 2) Reasonable estimation methods and assumptions to fill gaps in the observations.
- 3) Calibration of model parameters and unmeasured boundary conditions within reasonable bounds to improve agreement between simulated and observed water quality.
- 4) Model predicted results have been compared with the associated observed measurements using graphical presentations. Visual comparisons are useful in evaluating model performance over the appropriate temporal or spatial scales.
- 5) Goodness of fit statistics have been calculated comparing the model predicted results to the associated observed measurements.
- 6) Identification of key parameters/processes through model calibration and sensitivity analysis.
- 7) Clear communication of key assumptions during model development with the project team.
- 8) Clear written documentation of all important elements in the model, including model setup, boundary conditions, assumptions, and known areas of uncertainty.
- 9) Peer review.

SECTION VII: DOCUMENTATION IN MODEL REPORTS

The development and calibration of the extended Snake River - Hells Canyon CE-QUAL-W2 model, including updates, setup, and model outputs will be documented in the Model Development Report that will be provided after model calibration has been completed. The Model Development Report is a contractual obligation of Tetra Tech to EPA Region 10, but it is expected that both EPA and Oregon DEQ (and potentially other parties at the discretion of EPA) will provide review and comments. Tetra Tech will update the report based on the EPA and Oregon DEQ comments and submit a Final Model Development Report.

The Tetra Tech Task Order Leader (TOL) will maintain a central project file in Tetra Tech's Research Triangle Park, NC, office to contain all related documents, reports, communications, data compilations, checklists or other records, and deliverables (electronic files and hard copies). Electronic files and records will be stored on Tetra Tech's secure network which is regularly backed up internally and to an off-site server to preserve business continuity in the event of natural or other catastrophic events which may result in local or regional catastrophic failure or disruption. The TOL will retain all files for a period of no less than five years after final delivery.

SECTION VIII: PEER REVIEW

It is expected that the model and documentation will be subject to technical review from EPA, ODEQ, and IPC (and potentially other organizations) under Task 4. Tetra Tech will provide a response to technical review comments and perform any needed modifications to the model and report.

SECTION IX: MANAGEMENT SCENARIOS

The model will be used to estimate impacts from varied sources of thermal loading. The current Technical Directive includes the first two model scenarios below (“Free-flowing” and “No source”) along with the calibrated model representation of “Current conditions”. Additional source conditions will likely be assessed as the TMDL is developed as captured in items c – e in the following list:

- a. “Free-flowing” scenario where the three Hells Canyon Complex dams are mathematically removed, and free-flowing hydrodynamics and water quality conditions are simulated as well as restored riparian vegetative shading. This will require research and consultation to characterize geometry of the free-flowing channel. Both topographic and vegetative shading will need to be revised for the segments contained in the existing Hells Canyon Complex model, while restored vegetative shading will be represented in the additional model reaches upstream and downstream of the Hells Canyon Complex.
- b. “Restored vegetation” scenario that evaluates the stream temperature response with streamside vegetation at restored conditions.
- c. “Background” scenario with all known anthropogenic sources of thermal load removed. This scenario evaluates the stream temperature response from background sources only. Background sources include all sources of pollution or pollutants not originating from human activities. Background sources may also include anthropogenic sources of a pollutant that DEQ or another Oregon state agency does not have authority to regulate, such as pollutants emanating from another state, tribal lands, or sources otherwise beyond the jurisdiction of the state (OAR 340-042-0030(1)).
- d. “Tributary” scenario with “Current conditions” for all model inputs except for adjusted tributary temperatures. There are a variety of options for setting tributary mouth temperatures in a scenario. Alternatives include setting temperatures to applicable numeric temperature criteria for each tributary and/or adjusting temperatures by fixed increments to assess the impact of incremental changes in tributary mouth temperatures on mainstem Snake River temperatures. This latter approach would support evaluation of allocation of a fraction of the human use allowance to tributaries.
- e. “No point source” scenario with “Current Conditions” used for all model inputs except point sources, which are removed.
- f. “TMDL wasteload allocations” scenario with “Current Conditions” for all model inputs except point sources are set to the assigned wasteload allocation temperatures and flows.

Development of model scenarios will require additional consultation with EPA, ODEQ, and potentially other parties identified by EPA to develop scenario representations that align with TMDL allocations and assumptions.

SECTION X: PROJECT ORGANIZATION AND MANAGEMENT

X.A PROJECT TEAM ROLES

The project team, roles and responsibilities for key technical and quality management functions, and lines of authority and communication are described in Section I, Subsection I.B, Roles and Responsibilities.

X.B EXPERTISE AND SPECIAL TRAINING REQUIREMENTS

Tetra Tech staff involved in developing model input data sets and model application have experience in numerical modeling gained through their work on numerous similar projects. The Tetra Tech TOL, who has extensive experience managing similar projects, will provide guidance to the modeling. The TOL will ensure strict adherence to the project protocols.

Ms. Susan Lanberg is the QA Officer for this project. She is the QA Officer for Tetra Tech's WTR division and is the QA Officer for several contracts, including EPA contracts with the Office of Research and Development, Office of Science and Technology; and Office of Wetlands, Oceans, and Watersheds.

Dr. Jonathan Butcher, P.H. will serve as the Technical Lead. Dr. Butcher is a Professional Hydrologist with 36 years' experience as a consultant supporting EPA, state, and local governments throughout the US in TMDL water quality modeling, and water supply protection studies and is a nationally recognized expert in the application of the watershed and waterbody response models.

X.C REPORTS TO MANAGEMENT

This section identifies the role of senior management and key junctures of the project when the team will communicate progress and/or issues to agency management. In addition to communicating to management at key junctures, the project team should inform management of major deviations from the QAPP in a timely manner, such as delays in the model development schedule, changes in technical approach, and unforeseen data or model framework limitations.

The Tetra Tech TOL (or designee) will provide monthly progress reports to EPA and EPA will provide updates to the States of Oregon and Idaho. As appropriate, these reports will inform EPA of the following:

- Adherence to project schedule and budget
- Deviations from approved QAPP, as determined from project assessment and oversight activities
- The impact of any deviations on model application quality and uncertainty
- The need for and results of response actions to correct any deviations
- Potential uncertainties in decisions based on model predictions and data
- Data quality assessment findings regarding model input data and model outputs

X.D PROJECT SCHEDULE

The Snake River - Hells Canyon temperature TMDL Model Development project schedule is described in Task Order 1 of contract EP-C-17-046 and is provided in Table X-1.

Table X-1. Snake River - Hells Canyon Temperature TMDL Model Development: Deliverables and Deliverable Dates

Deliverable	Due Date
Task 1. Project Kickoff Call	Within 30 days of notice to proceed
Task 1. Summary of key points, outcomes, and action items from conference calls	Within 5 working days from each of the conference calls.
Task 2. Model Review technical memorandum	Within 2 months of receipt of model and associated documentation
Task 3. QAPP Development	Draft: Within 20 working days of kickoff call and within 20 working days of receipt of existing model and associated documentation, whichever is later. Final (signature ready): Within 10 working days of receipt of all comments from EPA and ODEQ.
Task 4. Model Development Report draft and one final	Draft 1: Within 9 months from approval of QAPP. Draft 2: Within 2 months of receipt of all comments on Draft 1. Final: Within 10 working days of receipt of all comments on Draft 2.
Task 5. Model Scenario Report, input/output files	Draft 1: Within 6 months of approval of Task 4 report. Draft 2: Within 2 months of receipt of all comments on Draft 1. Final: Within 10 working days of receipt of all comments on Draft 2.

SECTION XI: DATA MANAGEMENT

Tetra Tech will not conduct sampling (primary data collection) for this task. Secondary data collected as part of this task will be maintained as hardcopy only, both hardcopy and electronic, or electronic only, depending on their nature. All electronic data will be maintained on Tetra Tech's computers and servers.

Tetra Tech's computers are either covered by on-site service agreements or serviced by in-house specialists. When a problem with a microcomputer occurs, in-house computer specialists diagnose the problem and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. For other computer equipment requiring outside repair and not covered by a service contract, local computer service companies are used on a time-and-materials basis. Routine maintenance of microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes. All computer users have been instructed on the importance of routinely archiving Task Order data files from hard drive to compact disc or server storage. The office network server is backed up on tape nightly during the week. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems have been placed on all Tetra Tech computer systems and are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software is performed to keep up with evolutionary changes in computer storage, media, and programs.

SECTION XII: RECORDKEEPING AND ARCHIVING

Thorough documentation of all modeling activities is necessary to be able to effectively interpret the results. All records and documents relevant to the application, including electronic versions of data and input data sets, will be maintained at Tetra Tech's offices in the central file. The

central repository for the model will be Tetra Tech's Research Triangle Park, NC office. Tetra Tech will deliver a copy of the records and documents in the central file to EPA at the end of the task. Unless other arrangements are made, records will be maintained at Tetra Tech's offices for a minimum of five (5) years following task completion.

The Tetra Tech TOL and designees will maintain files, as appropriate, as repositories for information and data used in models and for preparing reports and documents during the task. Electronic project files are maintained on network computers and are backed up nightly. The Tetra Tech TOL will supervise the use of materials in the central files. The following information will be included in the hard copy or electronic task files in the central file:

- Any reports and documents prepared
- Contract and task order information
- QAPP and draft and final versions of requirements
- Electronic copies of models
- Results of technical reviews, internal and external design tests, quality assessments of output data, and audits
- Documentation of response actions during the task to correct problems
- Input and test data sets
- Communications (memoranda; internal notes; telephone conversation records; letters; meeting minutes; and all written correspondence among the task team personnel, suppliers, or others)
- Studies, reports, documents, and newspaper articles pertaining to the task
- Special data compilations

Records of receipt with information on source and description of documentation will be filed along with the original data sheets and files to ensure traceability. Records of actions and subsequent findings will be kept during additional data processing.

All data files, source codes, and executable versions of the computer software will be retained for internal peer review, auditing, or post-task reuse in the electronic task files in the administrative record. These materials include the following:

- Versions of the source and executable code used
- Databases used for model input, as necessary
- Key assumptions
- Documentation of the model code and verification testing for newly developed codes or modifications to the existing model

The Tetra Tech QC Officer and other experienced technical staff will review the materials listed above during internal peer review of modified existing models or new codes or models. The designated QC Officer will perform QC checks on any modifications to the source code used in the design process. All new input and output files, together with existing files, records, codes, and data sets, will be saved for inspection and possible reuse.

SECTION XIII: QAPP REVIEW AND APPROVAL

The TOCOR and TOL will lead distribution of the draft QAPP to their respective project teams. Comments from EPA and relevant reviewers will be provided to the TOL for further discussion

if appropriate, and revision and submittal of the final plan within 5 business days of receipt of EPA's comments. Following EPA approval, the TOCOR and TOL will distribute the final, signed copy to their respective staff assigned to the project. Official copies of the final, approved QAPP will be retained by the TOCOR and TOL. If any change(s) in the QAPP are required during the project, they must be described in a memorandum and approved by the signatories to this QAPP and attached to the QAPP.

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APPENDIX 1. TETRA TECH REVIEW OF PORTLAND STATE UNIVERSITY CE-QUAL-W2 MODEL OF HELLS CANYON RESERVOIR COMPLEX

Overall conclusions: The model achieves a generally excellent fit to observed water surface elevations and temperature profiles. Sources of most data supporting model development are adequately explained. The model is currently in draft form and it appears that some further revisions of the water temperature simulation in Hells Canyon Reservoir may occur.

Specific notes follow:

Bathymetry: The model was built using bathymetry from Idaho Power (IP), which was interpolated using Surfer and integrated with a digital elevation model (DEM) for the areas above normal pool. The report does not discuss the DEM resolution and age of the bathymetry or any potential changes over time; however, Idaho Power confirmed that “the majority of the bathymetric surveys were conducted from 2006 through 2008 with a multibeam echosounder” and are thus within a decade of the start of the modeling period.

The history of bathymetric measurements and sedimentation in Brownlee Reservoir is described in a 2018 poster presentation¹. Current rates of sedimentation in Brownlee are low due to the presence of 12 upstream dams on the Snake River and its tributaries and the low gradient of the portion of the river immediately upstream of Brownlee. Similarly, Brownlee is an effective sediment trap that will reduce sedimentation in Oxbow and Hells Canyon reservoirs. Thus, changes in bathymetry over time do not appear to be an issue for the temperature modeling.

Meteorology: The model covers calendar years 2014-2018. Weather stations in the area are limited and highly affected by topography. The weather data for the model were in large part obtained from predictions from the weather model WRF-NAM done for IPC. This was combined with USGS records of windspeed on Brownlee and data from an IPC met station at Brownlee Dam. The WRF-NAM run starts 5/11/2014; for the period prior to that (from January 2014) the model uses data from the Ontario AgriMet station. How well this matches WRF-NAM is not immediately clear, but this applies only for a short period. Cloud cover was back-calculated from solar radiation data. That approach is sufficient for daytime conditions but can’t be used for night cloud cover and what was done there is not explained. Portland State noted that final cloud cover of the day was assumed to apply over the succeeding night, which may introduce small discrepancies into the longwave heat exchange estimates.

For Oxbow and Hells Canyon reservoirs the WRF-NAM model predictions were not used directly, despite covering this area; instead, the meteorological data from Brownlee waterbody 5 were extended to this area. This was done because WRF-NAM did not correctly predict the air temperature relationship observed between Oxbow and Brownlee. The substitution does not appear to result in any major problems in predicting temperature profiles.

Reservoir Outflows: Measured data are used for turbine releases and spill from Brownlee. Calculated outflows rather than measured data are used for releases from Oxbow and Hells Canyon due to “high frequency variations in water level”. This reasoning does not match later

¹ Welcker, C., K. Anderson, and G. Carson. 2018. Fifty Years of Sediment Dynamics in a Large Reservoir in the Western US. G51C-0505. American Geophysical Union Fall Meeting.
https://www.researchgate.net/publication/329783270_Fifty_Years_of_Sediment_Dynamics_in_a_Large_Reservoir_in_the_Western_US

statements as p. 73 says for Oxbow “water level fluctuation is very small” and p. 74 for Hells Canyon “the water level fluctuation is very small in Hells Canyon Reservoir.” In addition, “Due to the high frequency variability of turbine flows out of Hells Canyon, a turbine baseflow of 200 m³/s was included in the model as a structure outflow to smooth out the turbine outflow and better match the measured data.”

In essence, the model is being forced to maintain consistency with observed water surface elevations in Oxbow and Hells Canyon and the measured releases from Brownlee at the expense of not matching observed releases from the latter two dams. This is common modeling practice and necessary to prevent drift in the mass balance of Oxbow and Hells Canyon; however, there is no guarantee that the resolution of the discrepancy is attributed to the correct source. For instance, there may be uncertainty in the measured outflow from Brownlee, or additional sources and sinks of water in Oxbow or Hells Canyon. From a practical standpoint relative to the TMDL this is important primarily if it affects the temperature predictions in the lower reservoir – which is uncertain without further sensitivity analysis.

PSU (pp. 51-52) provides only graphical timeseries comparisons of measured and modeled outflows from Oxbow and Hells Canyon. It would be preferable to also show scatter plots and statistics on the results of the correction.

Segmentation: The model segmentation appears reasonable, with good spatial resolution and run time of 5-6 hours for Brownlee (the largest and most complex reservoir). Finer resolution is provided in the outflow channel for Brownlee, which is the limiting area for the variable model time step.

The upstream end of Brownlee required some special attention as this area shifts from riverine to lacustrine conditions depending on the elevation of the reservoir. “To preserve the riverine section and allow that section to stratify as needed when water levels were high, the model grid was subdivided into multiple waterbodies that would not lose segments as the water level dropped. The upstream water bodies in Brownlee Reservoir allowed the system to transition from lacustrine to riverine as necessary by the change in pool and inflow”. During riverine conditions velocities in this area are on the order of 1 m/s and are sensitive to the channel Manning’s coefficient (p. 69). No direct data were available to constrain these friction coefficients, although they appear to result in a good fit to the temperature profiles.

Tributaries: There are five major tributaries to the reservoir complex in addition to the Snake River itself. All five have flow gages, although some are a distance upstream and require prorating. With the exception of Daly Creek, a smaller tributary to Brownlee, there are measured temperature data for the tributaries, although there are significant gaps in the record for Pine Creek (tributary to Hells Canyon) and Wildhorse River (tributary to Oxbow). Daly Creek is assumed to have the same temperature as Burnt River. Gaps in the Wildhorse data were filled using a linear regression equation between Wildhorse River temperatures and Powder River temperatures; gaps in the Pine Creek inflow temperatures were filled using a regression between Powder River and Pine Creek data.

Flow Calibration: Flow is calibrated primarily through matching observed water surface elevation (WSE). For Brownlee a good fit is obtained, but only after adding a water balance flow averaging about 5 m³/s to the downstream end of Brownlee as distributed tributary inflow to branch number 5. Water balance flows for some individual days are as high as about 500

m³/s. The need for these flows is attributed to ungaged tributaries, which seems reasonable, although no explanation of why they are added to the specific location chosen is provided, nor are error statistics for the model prior to adding the water balance flows. Net exchanges with ground water are also encompassed within the water balance flows. In response to questions, Portland State noted that “statistics were not calculated prior to adding the water balance since water balance flows were necessary to ensure that the model runs without any errors and has the correct surface area exposed to the atmosphere based on water level.” Portland State also noted “The error in water could be distributed along all the model branches, added to defined ungaged basins when there are positive flows, an adjustment to the inflow, or an adjustment to the outflow. There are minor differences in temperature when exploring these different options.”

The report does not state what temperatures are associated with the water balance flows added to Brownlee or how they were estimated. In response to a question about this, Portland State replied “Water temperatures are assigned to the water balance flow as a part of temperature calibration. A known temperature time series from another location is often used as a starting point. Snake River inflow temperatures were applied to the water balance flow. A sensitivity check was done using Burnt River temperatures with no appreciable difference in error statistics.” Examination of the distributed temperature input file for Branch 5 (ttr_tr3.csv) that the temperature series for the water balance flows are the same as are used for the upstream Snake River inputs (WTemp.Logger@Snake River_345).

Additional water balance flows are not assigned to Oxbow and Hells Canyon; however, as noted above, these already have implicit water balance flows reflecting the difference between modeled and measured outflows from these two dams.

Water Temperature Calibration: The outflow temperature calibration appears to achieve good results for each dam, with mean errors between -0.5 and +0.03 °C, mean absolute errors less than 0.9, and root mean squared errors up to 1.13 °C for the three reservoirs. Note that the observed data are continuous timeseries, so it may also be useful to report Nash-Sutcliffe coefficients of model fit efficiency, although Portland State indicated this had not been done. In general, the outflow temperatures look to be unbiased, except that the Hells Canyon predicted outflow temperatures may be too cold in winter (which would have little impact on the TMDL). Error statistics for individual seasons are not provided but would be useful. Portland State has offered to provide seasonal statistics on request.

Comparison to measured vertical temperature profiles is provided graphically in an appendix. These look quite good for Brownlee, with a close match to the full profile including the position of the metalimnion on most dates. No statistics are provided but the fit looks slightly less skilled for Hells Canyon where the model often predicts secondary stratification with warmer temperatures at the surface that are not seen in the observed data.

In response to a query, Portland State noted “We are still evaluating issues with meteorological data and impacts of the coffer dam on Hells Canyon temperature profiles.” This suggests that the draft model may undergo further revisions that could have an effect on the downstream temperature simulation.
