Handout, CVP Water Temperature Modeling Platform, Modeling Technical Committee Meeting #2

October 7, 2021; 1-4 p.m.

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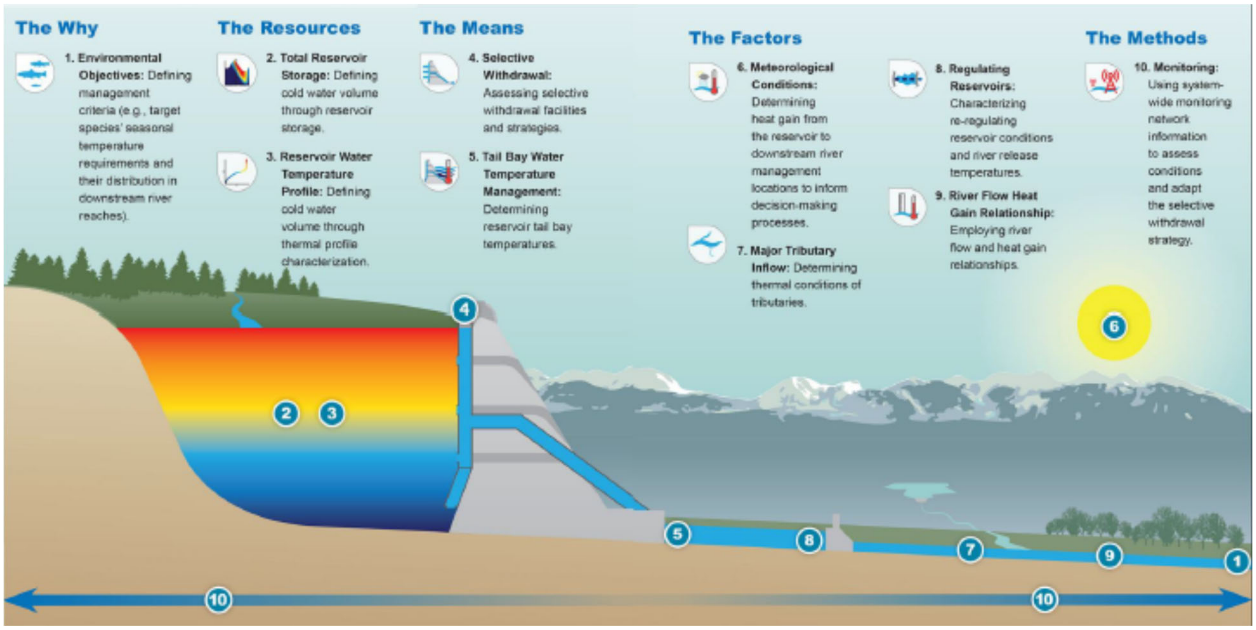

Elements of Water Temperature Management (Source: Reclamation, 2017. Water Temperature Management in Reservoir-River Systems through Selective Withdrawal, Reference Technical Memorandum for Central Valley Project Operation, California. September)

Agenda Topics for the MTC meetings (Subject to Change)

Key: 1 – Introductory Presentation; 2 – Comments and Discussion; 3 – Closure Discussion; TBD – To be determined

Topic	7-1-21	10-7-21	1-6-22	4-7-22	7-7-22	10-6-22	1-5-23	4-6-23	7-6-23	10-5-23
MTC Orientation	1/2/3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Project Purposes, Goals, Anticipated Outcomes	1/2/3	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Modeling Framework Selection	1	2	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Temperature Model Selection	1	2	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Consistency between System Model and Detailed Models	N/A	1	2	3	N/A	N/A	N/A	N/A	N/A	N/A
Common Model Preparation and Considerations	N/A	1	2/3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sacramento/Trinity River Water Temperature Model	N/A	N/A	1	2	2/3	3	N/A	N/A	N/A	N/A
American River Water Temperature Model	N/A	N/A	N/A	1	2	2/3	3	N/A	N/A	N/A
Stanislaus River Water Temperature Model	N/A	N/A	N/A	N/A	1	2	3	N/A	N/A	N/A
Modeling Framework Implementation	1	N/A	2	N/A	N/A	3	3	N/A	N/A	N/A
Phase II Activities	N/A	N/A	N/A	N/A	TBD	TBD	TBD	TBD	TBD	TBD
Peer Review Outcomes	N/A	N/A	N/A	N/A	1/2/3	N/A	N/A	N/A	N/A	1/2/3

Notes:

- The WTMP project period is through October 2023 with quarterly MTC meetings.
- Two rounds of peer reviews through the Delta Science Program are planned in Spring 2022 and Summer 2023.

Modeling Framework Evaluation Criteria

The following tables are excerpts from the draft Model Framework Selection TM and compiled here for convenience and for discussion only.

Table 4-1. Model framework evaluation criteria based on model types that may be utilized in the WTMP modeling framework

Criterion	Notes	Importance
CEQUAL-W2	Direct support for specific models expected to be used by Reclamation may significantly reduce the effort implementing the modeling framework.	Must
HEC-5Q	Direct support for specific models expected to be used by Reclamation may significantly reduce the effort implementing the modeling framework.	Prefer
HEC-ResSim	Direct support for specific models expected to be used by Reclamation may significantly reduce the effort implementing the modeling framework.	Prefer
HEC-RAS	Direct support for specific models expected to be used by Reclamation may significantly reduce the effort implementing the modeling framework.	Prefer
General command line models	Models typically run from a command line can generally be run in an automated mode on a server.	Must
General GUI based models	Models that are embedded within a user interface may be more difficult to automate from a modeling framework.	Prefer
Scripted processes	Many pre- and post-processing activities can be accomplished with scripts.	Must
Excel worksheets	Leveraging Excel-based tools such as the Jacobs WQ visualization worksheet may be advantages.	Prefer

Table 4-2. Model framework evaluation criteria based on types of model coupling utilized in modeling framework

Criterion	Notes	Importance
Loose coupling	Loose coupling allows one model output to pass as input to another model after completing simulation over a prescribed time window.	Must
Tight coupling	Tight coupling allows exchanges of data within model computation loops, typically relying on inter-process communication based on a common API such as Open Modeling Interface (OpenMI).	Unnecessary

Table 4-3. Model framework evaluation criteria based on forms of workflow control utilized when running a sequence of models in a modeling framework

Criterion	Notes	Importance
Linear sequence	Simple sequence where output from one model becomes input to the next model in the sequence.	Must
IF-THEN-ELSE conditionals	Branching structure based on conditional evaluation, useful to reduce run-time when some models do not need to be computed under all conditions.	Prefer
Loops	Iteration loops are the foundation for ensemble, Monte Carlo, and sensitivity simulations.	Prefer
Ensemble Sets	Running a set of simulations utilizing an ensemble of boundary conditions.	Prefer
Monte Carlo Iteration	Running a large set of simulations where boundary conditions are utilized.	Prefer
Sensitivity Analysis	Making a series of runs varying one or more model parameters over a given range.	Prefer
Uncertainty Analysis	Including computations to place confidence limits on model results.	Prefer

Table 4-4. Model framework evaluation criteria based on model configuration and time series data management application that may be utilized in a framework

Criterion	Notes	Importance
Data Acquisition	Collection, validation, and correction of new field data.	Prefer
Boundary Condition Management	Linking historical or planning time series data to models.	Must
Alternative Configurations	Managing model configuration files for existing or proposed conditions.	Must
Analysis Period Specifications	Managing model simulation periods.	Must
Simulation (run) Management	Managing and executing sets of model runs.	Must
Forecasting Support	Managing model configuration and output for regular forecasting.	Prefer
Planning Support	Organizing sets of input and output for a planning workflow.	Must
Configuration Version Control	Managing changes in model configuration data through version control.	Prefer
Posting and Archiving	Result posting and archiving.	Prefer
Distributable data and model versions	Allow selected data and models to be publicly distributed.	Must

Table 4-5. Model framework evaluation criteria based on user interface capabilities the framework can provide to improve the useability, efficiency, and transparency of modeling activities

Criterion	Notes	Importance
Configure model linking	Configure, manage, and display boundary condition and model-to-model linking.	Must
Model parameter editing	Editing of at least the primary model data.	Prefer
Run control	Provide user interface (UI) to facilitate run management.	Must

Criterion	Notes	Importance
Alternative Management	Provide a UI to manage alternatives.	Must
Plotting Results	Provide a UI to do at least basic visualization of model results.	Must
Reporting	Provide a UI to create at least basic reports.	Must
Workflow Guidance	Provide an interface to facilitate standard workflows.	Prefer

Table 4-6. Model framework evaluation criteria based on locations of model and framework configuration and time series data storage

Criterion	Notes	Importance
Desktop Workstation	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow.	Must
Local Server	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow.	Must
Cloud Server	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow.	Prefer

Table 4-7. Model framework evaluation criteria based on where computations are performed

Criterion	Notes	Importance
Desktop Workstation	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow and computational performance.	Must
Local Server	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow and computational performance.	Prefer
Cloud Server	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow and computational performance.	Prefer

Table 4-8. Model framework evaluation criteria based on type of software application model with which model operators will interact

Criterion	Notes	Importance
Desktop Application	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow.	Must
Web Application	Decision depends on preferred modeling team organization and IT infrastructure, and influences workflow.	Unnecessary

Modeling Framework Comparison

The following tables are excerpts from the draft TM and compiled here for convenience and for discussion only.

Table 5-1. Model framework comparison per criteria based on model types that may be utilized in the WTMP modeling framework

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
CEQUAL-W2	Must	C3	C3	Y*	C3	C3	C2	Y	C2
HEC-5Q	Prefer	C3	C3	C3	C3	C3	C2	C2	C2
HEC-ResSim	Prefer	C3	C3	C3	C3	Y	C2	Y	HEC-ResSim
HEC-RAS	Prefer	C3	C3	C3	C3	Y	C2	Y	Y
General command line models	Must	C3	C3	C3	C3	C2	C2	C2	C2
General GUI based models	Prefer	C3	C3	C3	C3	C3	C3	C3	C3
Scripted processes	Must	C3	C3	C3	C3	C2	C2	C1	C1
Excel worksheets	Prefer	C3	C3	C3	C3	C3	C3	C3	C3

Table 5-2. Model framework comparison per criteria based on type of model coupling utilized by a model framework

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Loose coupling	Must	Y	Y	Y	Y	Y	Y	Y	Y
Tight coupling	Unnecessary	Y	Y	Y	Y	C3	Y	C3	C3

Table 5-3. Model framework comparison per criteria based on forms of workflow control utilized when running a sequence of models in model framework

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Linear sequence	Must	Y	Y	Y	Y	Y	Y	Y	Y
IF-THEN-ELSE conditionals	Prefer	C3	C3	C1	C1	C3	C1	C2	C3
Loops	Prefer	C3	C3	C2	C2	Y*	C1	C2	C2
Ensemble Sets	Prefer	C3	C3	C3	C2	Y*	C3	C2	Y
Monte Carlo Iteration	Prefer	C3	C3	C3	C2	C3	C3	Y	C3
Sensitivity Analysis	Prefer	C3	C3	C3	C2	C3	C2	C2	C3
Uncertainty analysis	Prefer	C3	C3	C3	C2	C3	C2	C2	C3

Table 5-4. Model framework comparison per criteria based on model configuration and time series data management application that may be utilized in a framework

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Data Acquisition	Prefer	C3	C3	C3	C3	Y	C3	C2	Y
Boundary Condition Management	Must	C2	C2	C2	Y*	Y	Y	Y	Y
Alternative Configurations	Must	C2	C2	C2	C2	C2	Y	Y	Y
Analysis Period Specifications	Must	C2	C2	C2	C2	Y	C3	Y	Y
Simulation (run) Management	Must	C2	C2	C2	C2	Y	Y	Y	Y
Forecasting Support	Prefer	C3	C3	C3	C3	Y	C3	C2	Y
Planning Support	Must	C3	C3	C3	C3	C3	C3	Y	C2
Configuration Version Control	Prefer	C3	C3	C3	C3	C3	C3	C2	Y*
Result Posting and Archiving	Prefer	C3	C3	C3	C3	C3	C3	C2	Y
Distributable data and model versions	Must	Y	Y	Y	Y	Y	Y	Y	Y

Table 5-5. Model framework comparison per criteria based on user interface capabilities the framework can provide to improve the useability, efficiency, and transparency of modeling activities

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Configure model linking	Must	Y	Y*	Y	Y*	Y*	Y	Y	Y
Model parameter editing	Prefer	C3	C3	C3	C3	C2	C2	Y	Y
Run control	Must	C2	C2	C2	C2	Y	Y	Y	Y
Alternative Management	Must	C3	C3	C3	C3	C3	C3	Y	Y
Plotting Results	Must	C3	C3	C3	C3	Y	Y	Y	Y
Reporting	Must	C3	C3	C3	C3	C3	C2	C2	C2
Workflow Guidance	Prefer	C3	C3	C3	C3	C3	C3	C2	Y

Table 5-6. Model framework comparison per criteria based on locations of model and framework configuration and time series data storage

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Desktop Workstation	Must	Y	Y*	Y	C3	Y	Y	Y	Y
Local Server	Must	C2	Y*	C2	Y*	Y*	C2	C2	Y
Cloud Server	Prefer	C2	Y*	C2	Y*	Y*	C2	C2	C2

Table 5-7. Model framework comparison per criteria based on where computations are performed

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Desktop Workstation	Must	Y	Y*	Y	C3	Y	Y	Y	Y
Local Server	Prefer	Y	Y*	C2	Y	C2	C2	Y*	C2
Cloud Server	Prefer	Y*	Y*	C2	Y	C2	C2	Y*	C2

Table 5-8. Model framework comparison per criteria based on type of software application model with which model operators will interact

Key: Y – the framework provides good suitability for WTMP; Y* – the framework meets WTMP needs with some adjustment; C1, C2, and C3 – the framework can be customized to meet WTMP needs with relatively low, moderate, and high level, respectively, of effort of customization and coding.

Criterion	Importance	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Desktop Application	Must	Y*	Y*	Y*	C3	Y	Y	Y	Y
Web Application	Prefer	C3	C3	C3	Y*	C3	C3	C3	C3

Table 5-9. Primary development language for the framework. X indicates primary development language

Primary Development Language	Preference	OMS3/ CSIP	ESMF	Hydro-Couple	CSDMS	Delft-FEWS	Delta Shell	HEC-WAT	HEC-RTS
Java	Prefer	X	-	-	-	X	-	X	X
Python	Prefer	-	-	X	X	-	-	X	X
.NET	-	-	-	-	-	-	X	-	-
C/C++/FORTRAN	-	-	X	X	X	-	-	-	-

Model Selection Criteria

The following tables are excerpts from the draft Model Selection TM and compiled here for convenience and for discussion only.

Table 2-1. Model selection criteria for numerical models and assigned priority.

Criteria	Notes/Comments	Priority
Model type (River/Reservoir)	Need to effectively predict both reservoir water temperatures (vertical profile and release temperature for selective withdrawal operations) and river temperatures (longitudinal temperature gradients) to manage cold water supplies and downstream river temperatures at appropriate spatial and temporal resolution.	High
Number of dimensions (1, 2)	Consider project objectives, data requirements, and ability to represent physical processes spatially, including potential tradeoffs between lower dimensional representations for computational efficiency and higher dimension for higher spatial resolution/refinement of model results.	High
System geometric representation	Favor greater detail in reservoirs and river reaches in the vicinity of operational control points where physical water temperature processes and biological objectives are most important (e.g., spawning). Improved model accuracy leads to improved estimates of biological models (e.g., Temperature Dependent Mortality on Sacramento River).	High
Dynamic flow model	Desirable over steady-state representations. Hydrology and project operations are complex (e.g., Shasta TCD and Folsom Shutters) and occur over a range of time scales (hours, days, months).	High

Criteria	Notes/Comments	Priority
Water temperature representation	Use an approach that provides accurate water temperature modeling, calibration, and validation over a range of conditions, including challenging water temperature compliance conditions. A complete heat budget formulation is necessary.	High
Time step (capable of sub-daily)	Sub-daily required. Aquatic species experience diurnal water temperature signals and there is, in some cases, the need to estimate aquatic species impacts in downstream river reaches based on sub-daily temperature conditions (e.g., maximum daily water temperatures).	High
Computational performance consideration	Computation time is important. Screening or planning level tools might employ models with lower spatial resolution with longer time steps and shorter computational times, while refined tools might employ models with higher spatial resolution and shorter time steps with longer computational times. Screening and refined models will be used to explore an appropriate solution space to examine tradeoffs or to iterate to a desired tradeoff and to evaluate uncertainty in system forcing parameters. Select models for the WTMP that match project objectives (i.e., screening or refined).	High

Table 2-2. Model selection criteria based on model linkage capability and assigned priority

Criteria	Notes/Comments	Priority
Discrete component model or system model	Discrete component model representations (reservoirs or rivers) can be linked together to model a larger reservoir-river system. System models that represent networks of reservoir and river reaches can be used alone or in concert with discrete component models.	Medium
Modeling framework compatible	Model can receive information from other models and then pass results to other models that will be supported in the WTMP.	High/ Medium

Table 2-3. Model selection criteria based on model input and output capabilities and assigned priority

Criteria	Notes/Comments	Priority
Pre-processor	Prefer models with pre-processors to assess and manage inputs, explore uncertainty, and minimize setup errors.	High
Post-processor	Prefer models with post-processors to assess, visualize, and manipulate output (graphical and tabular).	High
Data structure facilitates model calibration/ application	Model includes a data structure that is easily accessible to facilitate input, data storage, and output to facilitate modeling, calibration, and error detection.	Low

Table 2-4. Model selection criteria based on model support and assigned priority

Criteria	Notes/Comments	Priority
Model applications	Model has been used in applications similar to this project.	High
Actively supported	Actively supported models both in terms of tool usability (e.g., support) and longevity.	High
Public domain, peer reviewed, and accessible model modifications	Software should be in the public domain, peer reviewed, and include a mechanism to assess critical model assumptions and verify model modifications.	High
Free of charge	Model is free or is there a minimal cost for software and/or support.	High
Documentation	Required at a level that allows stakeholder and peer review and that provides a defensible final product. Documentation includes both technical reports on model construction (equations, solution methods) and user manuals.	High
Training and/or user group	For long-term use, available training and/or active user group forums to support ongoing model application.	Medium/ Low

Table 2-5. Model selection criteria based on specific features of current or planned CVP facilities and assigned prior

Criteria	Notes/Comments	Priority
Temperature control curtains	Lewiston Lake and Whiskeytown Lake contain temperature control curtains.	High
Submerged weirs/dams	There is a submerged dam upstream of New Melones Dam.	High
Selective withdrawal	Shasta Lake and Folsom Lake include selective withdrawal facilities.	High
Automated simulations to meet downstream temperature targets: tailbay	An ability to model target reservoir release temperatures.	Hig
Automated simulations to meet downstream temperature targets: river reach	An ability to model target downstream river temperatures.	High
Shade	Topographic and/or riparian vegetation shade.	Medium

Table 2-6. Model selection criteria based on qualitative modeling elements and assigned prior

Criteria	Notes/Comments	Priority
Ease of use	Model is relatively easily operated (data input, model run, and output accessed).	Medium
Credibility	Final model has sufficient documentation, peer review, application, and stakeholder support to be a credible tool to support temperature management.	High
Easy to incorporate uncertain input parameters	Model can readily assess uncertainty with the ability to modify inputs to assess uncertainty preferred over internal logic to assess uncertainty.	Medium
Collaboration with model developers	Model developers have an interest in the model application and potential opportunities to collaborate on model and WTMP development.	Med

Reviewed Models

The following tables are excerpts from the draft Model Selection TM and compiled here for convenience and for discussion only.

Table 3-1. Reservoir and system models reviewed for WTMP application

Model	Sponsor[1]	URL	Citation(s)
CE-QUAL-W2	PSU, USACOE	http://cee.pdx.edu/w2/	Cole, T. M., & Wells, S. A. 2008. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.6. Prepared for U.S. Army Corps of Engineers, Washington, DC 20314-1000. Wells, S. A., Editor. 2020."CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 4.2, user manual part 1, introduction," Department of Civil and Environmental Engineering, Portland State University, Portland, OR. (http://www.ce.pdx.edu/w2/) Wells, S. A. 2020. "CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 4.2.2, user manual part 5, model utilities and release notes," Department of Civil and Environmental Engineering, Portland State University, Portland, OR (http://www.ce.pdx.edu/w2/)
DYRESM	CWR-UWA	http://www.colby.edu/chemistry/EastPond/East_Pond/DYRESM_Model.html	Antenucci, J., and A. Imerito. 2003. The CWR Dynamic Reservoir Simulation Model DYRESM: User Manual. Centre for Water Research: The University of Western Australia.
HEC-5Q	USACOE	(unsupported)	U.S. Army Corps of Engineers, Hydrologic Engineering Center. 1986. HEC-5Q: System Water Quality Modeling. TP-111. January. (https://www.hec.usace.army.mil/publications/TechnicalPapers/TP-111.pdf) U.S. Army Corps of Engineers, Hydrologic Engineering Center. 1986. HEC-5: Simulation of Flood Control and Conservation Systems – Appendix on Water Quality Analysis. CPD-5Q. January. (https://www.hec.usace.army.mil/publications/ComputerProgramDocumentation/HEC-5Q_UsersManual_(CPD-5Q).pdf)
HEC-ResSim	USACOE	https://www.hec.usace.army.mil/software/hec-ressim/	U.S. Army Corps of Engineers, Hydrologic Engineering Center. 2021. HEC-ResSim: Reservoir System Simulation – User's Manual (Version 3.3). CPD-82. February. (https://www.hec.usace.army.mil/software/hec-ressim/documentation/HEC-ResSim_33_UsersManual.pdf) Additional citations at: https://www.hec.usace.army.mil/software/hec-ressim/documentation.aspx
Riverware	CADSWES	http://cadswes.colorado.edu/riverware/	Zagona, E., T. Magee, D. Frevert, T. Fulp, M. Goranflo and J. Cotter (2005). "RiverWare." In: V. Singh & D. Frevert (Eds.), Watershed Models, Taylor & Francis/CRC Press: Boca Raton, Florida, pp. 527–548. Zagona, E., T. Fulp, R. Shane, T. Magee, and H. Goranflo (2001), "RiverWare: A Generalized Tool for Complex Reservoir Systems Modeling,"

[1] Sponsors:
CADWES: Center for Advanced Decision Support for Water and Environmental Systems
CWR-UWA: Center for Water Resources, University of Western Australia
PSU: Portland State University
USACOE: US Army Corps of Engineers

Table 3-2. River models reviewed for WTMP application

Model	Sponsor[1]	URL	Citation(s)
CE-QUAL-RIV1	USACOE	https://erdc-library.erdc.dren.mil/jspui/handle/11681/4352	Army Corps of Engineers. 1990. CE-QUAL-RIVI: A Dynamic, One-Dimensional (Longitudinal) Water Quality Model for Streams, User's Manual. Instruction Report E-90-1
EPD-RIV1	GEPD	http://epdsoftware.wileng.com/	Martin, J.L and T. Wool. 2001. Dynamic One-Dimensional Model of Hydrodynamics and Water Quality - EPD-RIV1 User's Manual (Version 1.0). Prepared for Georgia Environmental Protection Division, Atlanta, Georgia.
Heat Source	ODEQ	https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Tools.aspx	Boyd, M., and Kasper, B. 2003. Analytical methods for dynamic open channel heat and mass transfer: Methodology for heat source model Version 7.0.
HEC-5Q	USACOE	(unsupported)	U.S. Army Corps of Engineers, Hydrologic Engineering Center. 1986. HEC-5Q: System Water Quality Modeling. TP-111. January. (https://www.hec.usace.army.mil/publications/TechnicalPapers/TP-111.pdf) U.S. Army Corps of Engineers, Hydrologic Engineering Center. 1986. HEC-5: Simulation of Flood Control and Conservation Systems – Appendix on Water Quality Analysis. CPD-5Q. January. (https://www.hec.usace.army.mil/publications/ComputerProgramDocumentation/HEC-5Q_UsersManual_(CPD-5Q).pdf)
HEC-RAS	USACOE	https://www.hec.usace.army.mil/software/hec-ras/	U.S. Army Corps of Engineers, Hydrologic Engineering Center. 2021. HEC-RAS River Analysis System, User's Manual (Version 6.0). CPD-68. May. (https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Users_Manual.pdf) Additional citations at: https://www.hec.usace.army.mil/software/hec-ras/documentation.aspx and https://www.hec.usace.army.mil/confluence/rasdocs
HEC-ResSim	USACOE	https://www.hec.usace.army.mil/software/hec-ressim/	U.S. Army Corps of Engineers, Hydrologic Engineering Center. 2021. HEC-ResSim: Reservoir System Simulation – User's Manual (Version 3.3). CPD-82. February. (https://www.hec.usace.army.mil/software/hec-ressim/documentation/HEC-ResSim_33_UsersManual.pdf) Additional citations at: https://www.hec.usace.army.mil/software/hec-ressim/documentation.aspx
QUAL2K	Tufts Univ., USEPA, WDOE	http://www.qual2k.com/home/default.html	Chapra, S.C., Pelletier, G.J. and Tao, H. 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA., Steven.Chapra@tufts.edu (http://www.ecs.umass.edu/cee/reckhow/courses/577/Qual2/Q2KDocv2_11b8%20v211.pdf)
RAFT	NOAA-SFSC	https://oceanview.pfeg.noaa.gov/CVTEMP/river/model	Daniels, Miles E., V.K. Sridharan, S.N. John, and E.M. Danner. 2018. Calibration and validation of linked water temperature models for the Shasta Reservoir and the Sacramento River from 2000 to 2015. NOAA Technical Memorandum NMFS-SWFSC-597. 60 p. Additional references at: https://oceanview.pfeg.noaa.gov/CVTEMP/reference
RBM10	USEPA	N/A	U.S. Environmental Protection Agency. 2018. EPA Fact Sheet: River Basin Model-10. (https://www.epa.gov/sites/production/files/2018-05/documents/columbia-snake-tmdl-rbm10-fact-sheet.pdf) Contact: Ben Cope U.S. EPA Region 10 Modeling Lead cope.ben@epa.gov (206) 553-1442 Jones, E.C., Perry, R.W., Risley, J.C., Som, N.A., and Hetrick, N.J., 2016, Construction, calibration, and validation of the RBM10 water temperature model for the Trinity River, northern California: U.S. Geological Survey Open-File Report 2016–1056, 46 p. (https://pubs.usgs.gov/of/2016/1056/ofr20161056.pdf)

Model	Sponsor[1]	URL	Citation(s)
River Modeling System (ADYN/RQUAL	Loginetics	http://www.loginetics.com/index.html	Hauser, G.E. and Walters, M. 1995. User's Manual for One-Dimensional Unsteady Flow and Water Quality Modeling in River Systems with Dynamic Tributaries. WR28-3-590-135. TVA Engineering Laboratory. Norris, Tennessee. July.
Riverware	CADSWES	http://cadswes.colorado.edu/riverware/	Zagona, E., T. Magee, D. Frevert, T. Fulp, M. Goranflo and J. Cotter (2005). "RiverWare." In: V. Singh & D. Frevert (Eds.), Watershed Models, Taylor & Francis/CRC Press: Boca Raton, Florida, pp. 527–548. Zagona, E., T. Fulp, R. Shane, T. Magee, and H. Goranflo (2001), "RiverWare: A Generalized Tool for Complex Reservoir Systems Modeling," Journal of the American Water Resources Association, AWRA 37(4):913–929.
RMA2/ RMA4	Aqueveo	https://www.aquaveo.com/	Donnell, B. P., Joseph V., W. H. McAnally, and others. 2011. "Users Guide for RMA2 Version 4.5," 27 Sept (https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.369.548&rep=rep1&type=pdf) Joseph V., Donnell, B.P., and others. 2008 "Users Guide for RMA4 Version 4.5", 14 Aug (https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.193.9679&rep=rep1&type=pdf)

Table 3-3. Sediment transport models that were reviewed but excluded from WTMP applications

Model	Sponsor[1]	URL
SRH-2D	USBR	https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.htm
Adaptive Hydraulics Model	USACOE	https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476708/adaptive-hydraulics-model-system/

Table 3-4. Three-dimensional reservoir models that were reviewed but excluded from WTMP applications

Model	Sponsor[1]	URL
Environmental Fluid Dynamics Code (EFDC)	USEPA	https://www.epa.gov/ceam/environmental-fluid-dynamics-code-efdc
AQUATOX	USEPA	https://www.epa.gov/ceam/aquatox
Delft3D-FM	Deltares	https://oss.deltares.nl/web/delft3d/
Semi-implicit Cross-scale Hydroscience Integrated System Mode (SCHISM)	Virginia Institute of Marine Sciences	https://www.vims.edu/ccrm/research/modeling/schism/index.php
Stanford Unstructured Nonhydrostatic Terrain-following Adaptive Navier-Stokes Simulator (SUNTANS)	Stanford University	https://web.stanford.edu/group/suntans/cgi-bin/documentation/user_guide/user_guide.html

[1] Sponsors:
USEPA: US Environmental Protection Agency
CADWES: Center for Advanced Decision Support for Water and Environmental Systems
GEPD: Georgia Environmental Protection Division
NOAA-SFSC: National Oceanic and Atmospheric Administration-Southwest Fisheries Science Center
ODEQ: Oregon Department of Environmental Quality
USACOE: US Army Corps of Engineers
USEPA: US Environmental Protection Agency
WDOE: Washington Department of Ecology

Model Evaluation Based on Selection Criteria

The following tables are excerpts from the draft Model Selection TM and compiled here for convenience and for discussion only.

NA=Not applicable; Long=Longitudinal; Vert=Vertical; Latl=Lateral

Table 3-5. System and reservoir models reviewed for WTMP application based on numerical model criteria

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Model type (Discrete/ System)	Is the model a discrete model or a system model?	NA	Discrete	Discrete	System	System	System
Model type (River/Reservoir)	Is the model designed for predicting vertical distributions and release-water temperatures in a reservoir reach?	Require	Yes	Yes	Yes	Yes	Yes
Short-term forecasting	Within season (days, weeks, months)	Require	Yes	Yes	Yes	Yes	Yes
Long-term planning	Extended simulations (years, decades)	Require	Yes*	Yes*	Yes	Yes	Yes
Number of dimensions (1, 2)	-	NA	2	1	1	1	1
System geometric representation	Principal dimension(s): longitudinal/ vertical	NA	Long/Vert	Vert	Long	Long	Vert
System geometric representation	Detailed vertical resolution? (Yes/No)	Require	Yes	Yes	Yes	Yes	No
Dynamic flow model	Yes/No	Prefer	Yes	No	Yes	Yes	No

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Water temperature representation	Full heat budget: Yes/No	Require	Yes	Yes	No	Yes	Yes
Time step (capable of sub-daily)	Yes/No	Require	Yes	Yes	Yes	Yes	Yes
Computational performance consideration	Faster/Slower	N/A	Slower	Faster	Faster	Faster	Unknown

Table 3-6. System and reservoir models reviewed for WTMP application based on criteria for model linkage capabilities

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Discrete component model or system model	Discrete/System	NA	Discrete	Discrete	System/Discrete	System/Discrete	System
Modeling framework compatible	Readily incorporated into a framework. Yes/No	Prefer	Yes	Unknown	Yes	Yes	Yes

Table 3-7. System and reservoir models reviewed for WTMP application based criteria for model input and output capabilities

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Pre-processor	Yes/No	Prefer	Yes	Yes	No	Yes	Unknown
Post-processor	Yes/No	Prefer	Yes	Yes	Yes	Yes	Yes
Data structure facilitates model calibration/application	Yes/No	Prefer	Yes	Unknown	Yes	Yes	Yes

Table 3-8. System and reservoir models reviewed for WTMP application based on criteria for model support

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Similar model applications	Many/Few/ None	Prefer	Many	Unknown	Many	Few	Unknown
Actively supported	Yes/No	Require	Yes	Yes	No	Yes	Yes
Public domain (PD), peer reviewed (PR), or accessible modifications (AM)	PD/PR/AM	Require	PD/PR/AM	PR	PD/AM	PD/PR/AM	PR
Documentation	Yes/No	Require	Yes	Yes	Yes	Yes	Yes
Training and/or user group	Yes/No	Prefer	Yes	Yes	No	Yes	Yes

Table 3-9. System and reservoir models reviewed for WTMP application based on criteria for specific features of current or planned CVP facilities

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Temperature control curtains	Yes/No	Require	Yes	No	No	No	No
Submerged weirs/dams	Yes/No	Require	Yes	No	Yes	Yes	No
Selective withdrawal	Yes/No	Require	Yes	Yes	Yes	Yes	Unknown
Automated simulations to meet downstream temperature targets: tailbay	Yes/No	Require	Yes	Unknown	Yes	Yes	Unknown
Automated simulations to meet downstream temperature targets: river reach	Yes/No	Prefer	NA	NA	Yes	Yes	Unknown
Shade	Yes/No (v=vegetation, t=topographic)	Prefer	Yes (t)	Unknown	Yes (v)	Yes (v)	No

Table 3-10. System and reservoir models reviewed for WTMP application based on criteria for qualitative modeling elements

Criteria	Comments	Need	CE-QUAL-W2	DYRESM	HEC-5Q	HEC-ResSim	Riverware
Ease of use	Less/ More Difficult	Prefer	More	Unknown	More	Unknown	Unknown
Credibility	Yes (supported)/ No (unsupported)	Prefer	Yes	Yes	No	Yes	Yes
Easy to incorporate uncertain input parameters	Yes/ No	Prefer	Yes	Yes	Yes	Yes	Unknown
Collaboration with model developers	Yes/ No	Prefer	Yes	Yes	Yes	Yes	Yes

Table 3-11. River models reviewed for WTMP application based on numerical model criteria

Long=Longitudinal; Vert=Vertical; Latl=Lateral

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
Model type (River/ Reservoir)	Is the model designed for predicting vertical distributions and release-water temperatures in a reservoir reach?	Require	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Short-term forecasting	Within season (days, weeks, months)	Require	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Long-term planning	Extended simulations (years, decades)	Require	No	No	No	No	Yes	No	Yes	No	Unknown	Yes	No	Yes	No
Number of dimensions (1, 2)	1/ 2	NA	1	1, 2	1	1	1	1	1	1	1	1	1, 2	1	1
System geometric representa-tion	Principal dimension(s): longitudinal/ lateral/vertical	NA	Long	Long/Vert	Long	Long	Long	Long	Long	Long	Long	Long	Long/ Latl	Long	Long
Dynamic flow model	Yes/No	Prefer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Water temperature representa-tion	Full heat budget: Yes/No	Require	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time step (capable of sub-daily)	Yes/No	Require	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Computational performance consideration	Faster/Slower	NA	Faster	Slower	Faster	Faster	Faster	Faster	Faster	Faster	Faster	Faster	Slower	Un-known	Faster

Table 3-12. River models reviewed for WTMP application based on criteria for model linkage capabilities

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
System model or discrete reach	System (Sis)/ Discrete (Dis)	NA	Dis	Dis	Dis	Dis	Sys/ Dis	Dis	Sys/ Dis	Dis	Dis	Dis	Dis	Sys/ Dis	Dis
Modeling framework compatible	Readily incorporated into a framework: Y/N	Prefer	Yes	Yes	Unknown	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3-13. River models reviewed for WTMP application based criteria for model input and output capabilities

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
Pre-processor	Yes/No	Prefer	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Unknown	Yes	Yes	Unknown	Unknown
Post processor	Yes/No	Prefer	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unknown	Yes	Yes	Yes
Data structure facilitates model calibration/ application	Yes/No	Prefer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3-14. River models reviewed for WTMP application based on criteria for model support

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
Similar model applications	Many/ Few	Prefer	Few	Many	Few	Many	Many	Few	Few	Many	Few	Few	Many	Unknown	Many
Actively supported	Y/N	Require	No	Yes	Unknown	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Public Domain (PD), Peer Reviewed (PR), or Accessible Modifications (AM)	PD/PR/AM	Require	PD/PR/ AM	PD/PR/ AM	PD/PR/ AM	PD/PR/ AM	PD/AM	PD/PR/ AM	PD/PR/ AM	PD/PR/ AM	PD/PR	PD/PR/ AM	PR	PR	PR
Documentation	Y/N	Require	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Training and/or User Group	Y/N	Prefer	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No

Table 3-15. River models reviewed for WTMP application based on criteria for model support

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
Temperature control curtains	Yes/ No	Require	NA	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Submerged weirs/dams	Yes/ No	Require	NA	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Selective withdrawal	Yes/ No	Require	NA	NA	N/A	N/A	N/A	NA	NA	NA	NA	NA	NA	NA	NA
Automated simulations to meet downstream temperature targets: tailbay	Yes/No	Require	NA	NA	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Automated simulations to meet downstream temperature targets: river reach	Yes/No	Prefer	NA	NA	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Shade	Yes/No (v=vegetation, t=topographic)	Prefer	No	Yes (t)	No	Yes (v,t)	Yes (v)	Yes (v)	Unknown	Yes (v)	Unknown	No	Yes (v,t)	No	Yes (v)

Table 3-16. River models reviewed for WTMP application based on criteria for qualitative modeling elements

Criteria	Comment	Need	CE-QUAL-RIV1	CE-QUAL-W2	EPD-Riv1	Heat Source	HEC-5Q	HEC-RAS	HEC-ResSim	QUAL-2K	RAFT	RBM10	RMA1/ RMA4	River-ware	RMS (ADYN/ RQUAL)
Ease of use	Less/More Difficult	Prefer	More	More	More	Unknown	More	Unknown	Unknown	Unknown	Unknown	Unknown	More	Unknown	Unknown
Credibility	Yes/ No (supported/ unsupported)	Prefer	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Model developer collaboration	Yes/ No	Prefer	Unknown	Yes	Unknown	Unknown	Yes	Yes	Yes	Unknown	Yes	Unknown	Yes	Unknown	Unknown
Uncertainty incorporation	Yes/ No	Prefer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes