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Spokane River in Idaho and Washington TMDL Water Quality and Hydrodynamic Modeling Quality Assurance Project Plan – DRAFT

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Spokane River in Idaho and Washington TMDL Water Quality and Hydrodynamic Modeling Quality Assurance Project Plan **DRAFT**

Prepared for:

U. S. Environmental Protection Agency Region 10

Prepared by:

Scott Wells and Chris Berger

Portland State University

USEPA Order Number EP090000068

February 2, 2009

Version 1

Section A – Project Management

A1 Approval Page

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US EPA Region 10 Watershed Unit

Date

Technical Project Manager

Ben Cope
US EPA Region 10 Watershed Unit

Date

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A3 Distribution List

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A4 Project/Task Organization

Mark Filippini is the EPA Region 10 Task Order Manager (TOM). Mr. Filippini will provide overall project oversight for this project as the EPA Contracting Officer's Representative (COR) or Task Order Manager (TOM). Mr. Filippini will work with Scott Wells, to ensure that the project objectives are attained. He will also review and approve the QAPP and other materials developed by the Portland State University to support the project, as well as coordinating with contractors, reviewers, and others to ensure technical quality and contract adherence.

Ben Cope is the EPA Region 10 Technical Project Manager. Ben Cope is the team leader for water quality modeling for the Spokane River dissolved oxygen project, which is a collaborative effort between EPA, the states of Washington and Idaho, and the Spokane Tribe. His responsibilities include planning and review of PSU work products.

Dr. Scott Wells is the Project Manager and Technical Lead for this project. He is accountable for Portland State University's overall performance on this contract and this specific task order. Dr. Wells, as project manager, is responsible for planning, directing, and controlling each task and ensuring the progress is commensurate with project scope, budget, and schedule. He is responsible for day-to-day communication with the project staff and the EPA TOM, for reviewing all draft and final products, preparing written correspondence to the EPA TOM, and for addressing any deviations from schedule, budget, or work quality. Dr. Wells is also responsible for overseeing all technical aspects of updating the model. Dr. Wells will be supported by Dr. Chris Berger. They will be responsible for updating the model, checking model calibration, applying the model for the scenarios runs, and writing of a final report(s). They will implement the QA/QC program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation.

A5 Project Description and Background

Background

The Upper Spokane River system is located in the Northeastern part of Washington State and runs from Coeur d'Alene Lake, Idaho at RM (River Mile) 111.3 downstream to Long Lake dam at RM 32.5. The Washington Department of Ecology will issue a DO TMDL for the Spokane River from the Idaho border to Long Lake Dam. EPA will issue NPDES permits to wastewater treatment plants on the Idaho portion of the Spokane River, and the Idaho Department of Environmental Quality will issue 401 certifications for those permits. The Spokane Tribe is currently developing a model of Spokane Arm, downstream of the project area, to assess water quality impacts in its jurisdictional waters. The TMDL, along with a 401 certification for the FERC relicensing of Spokane River dams, will reduce phosphorus loadings and affect minimum in-stream flows in the Spokane River.

An existing CE-QUAL-W2 water quality of models (Washington and Idaho) of Upper Spokane River will be combined and updated to the more recent version 3.6. The combined model will be used to help determine the impact of the TMDL and the FERC relicensing on the Spokane River water quality. The models were originally developed by Portland State University for the Washington Department of Ecology and EPA to simulate temperature, dissolved oxygen, nutrients, algae, and organic matter. The updated model will simulate the year 2001.

Prior reports prepared for the Spokane River modeling in Washington and Idaho include:

- Annear et al. (2001) - Upper Spokane River Model: Boundary Conditions and Model Setup for 1991 and 2000
- Berger et al. (2002) - Upper Spokane River Model: Calibration for 1991 and 2000
- Slominski et al. (2002) - Upper Spokane River Model: Boundary Conditions and Model Setup for 2001 where information such as the following were detailed:
 1. Inflows, temperatures, and water quality
 2. Meteorological conditions
 3. Bathymetry of the Spokane River and Long Lake and the model grid
 4. Reservoir operations and structure information
- Berger et al. (2003) - Upper Spokane River Model: Calibration for 2001
- Berger et al. (2003)- Upper Spokane River Model in Idaho: Boundary Conditions and Model Setup for 2001

Objectives

The focus of this present study is to perform the following tasks:

- Converting the Upper Spokane River CE-QUAL-W2 models (Washington and Idaho) to version 3.6
- Combining the Washington and Idaho models
- Reviewing and updating model boundary conditions
- Check model calibration
- Meet with stakeholders

- Develop and Run Modeling Scenarios
- Create reports on calibration and scenario runs

Model Capabilities

CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model developed by the US Army Corps of Engineers and the Water Quality Research Group at Portland State University. It has been applied to over a thousand systems, including rivers, lakes, reservoirs, estuaries, and combinations thereof. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies such as Lake Roosevelt that exhibit longitudinal and vertical water quality gradients. CE-QUAL-W2 consists of directly coupled hydrodynamic and water quality transport models. CE-QUAL-W2 simulates parameters such as temperature, algae concentration, dissolved oxygen concentration, pH, nutrient concentrations, organic matter and detention time.

CE-QUAL-W2 has been under continuous development since 1975. The original model was known as LARM (**L**aterally **A**veraged **R**eservoir **M**odel) developed by Edinger and Buchak (1975). The first LARM application was on a reservoir with no branches. Subsequent modifications to allow for multiple branches and estuarine boundary conditions resulted in the code known as GLVHT (**G**eneralized **L**ongitudinal-**V**ertical **H**ydrodynamics and **T**ransport Model). Addition of the water quality algorithms by the Water Quality Modeling Group at the US Army Engineer Waterways Experiment Station (WES) resulted in CE-QUAL-W2 Version 1.0. Version 2.0 was a result of major modifications to the code to improve the mathematical description of the prototype and increase computational accuracy and efficiency. The current version (version 3.6) includes additional improvements to the numerical solution scheme and water quality algorithms, as well as extending the utility of the model to provide state-of-the-art capabilities for modeling entire water basins in two-dimensions (Cole and Wells, 2008).

Model capabilities are summarized below:

Hydrodynamics: The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density and cannot be turned off.

Water Quality: Any combination of constituents can be included/excluded from a simulation. The effects of salinity or total dissolved solids/salinity on density and thus hydrodynamics are included only if they are simulated in the water quality module. The water quality algorithm is modular allowing constituents to be easily added as additional subroutines. The current version includes the following water quality state variables in addition to temperature:

1. any number of generic constituents defined by a 0 and/or a 1st order decay rate and/or a settling velocity and/or an Arrhenius temperature rate multiplier that can be used to define any number of the following:
 - a. conservative tracer(s)
 - b. water age or hydraulic residence time
 - c. coliform bacteria(s)
 - d. contaminant(s)
2. any number of inorganic suspended solids groups

3. any number of phytoplankton groups
4. any number of periphyton/epiphyton groups
5. any number of CBOD groups
6. ammonium
7. nitrate+nitrite
8. bioavailable phosphorus (commonly represented by orthophosphate or soluble reactive phosphorus)
9. labile dissolved organic matter
10. refractory dissolved organic matter
11. labile particulate organic matter
12. refractory particulate organic matter
13. total inorganic carbon
14. alkalinity
15. total iron
16. dissolved oxygen
17. organic sediments
18. gas entrainment
19. any number of macrophyte groups
20. any number of zooplankton groups
21. labile dissolved organic matter-P
22. refractory dissolved organic matter-P
23. labile particulate organic matter-P
24. refractory particulate organic matter-P
25. labile dissolved organic matter-N
26. refractory dissolved organic matter-N
27. labile particulate organic matter-N
28. refractory particulate organic matter-N

Additionally, over 60 derived variables including pH, TOC, DOC, TON, TOP, DOP, etc. can be computed internally from the state variables and output for comparison to measured data.

Long term simulations: The water surface elevation is solved implicitly, which eliminates the surface gravity wave restriction on the timestep. This permits larger timesteps during a simulation resulting in decreased computational time. As a result, the model can easily simulate long term water quality responses.

Head boundary conditions: The model can be applied to estuaries, rivers, or portions of a waterbody by specifying upstream or downstream head boundary conditions.

Multiple branches: The branching algorithm allows application to geometrically complex waterbodies such as dendritic reservoirs or estuaries.

Multiple waterbodies: The model can be applied to any number of rivers, reservoirs, lakes, and estuaries linked in series.

Variable grid spacing: Variable segment lengths and layer thicknesses can be used allowing specification of higher resolution where needed. Vertical grid spacing can vary in thickness between waterbodies.

Water quality independent of hydrodynamics: Water quality can be updated less frequently than hydrodynamics thus reducing computational requirements. However, water quality is *not* decoupled from the hydrodynamics (i.e., separate, standalone code for hydrodynamics and water quality where output from the hydrodynamic model is stored on disk and then used to specify advective fluxes for the water quality computations). Storage requirements for long-term hydrodynamic output to drive the water quality model are prohibitive for anything except very small grids. Additionally, reduction in computer time is minimal when hydrodynamic data used to drive water quality are input every time step.

Auto-stepping: The model includes a variable timestep algorithm that attempts to help ensure stability requirements for the hydrodynamics imposed by the numerical solution scheme are not violated.

Restart provision: The user can output results during a simulation that can subsequently be used as input. Execution can then be resumed at that point. Note that this feature has not been updated for the latest version but will be included in the next release.

Layer/segment addition and subtraction: The model will adjust surface layer and upstream segment locations for a rising or falling water surface during a simulation.

Multiple inflows and outflows: Provisions are made for inflows and inflow loadings from point/nonpoint sources, branches, and precipitation. Outflows are specified either as releases at a branch's downstream segment or as lateral withdrawals. Although evaporation is not considered an outflow in the strictest sense, it can be included in the water budget.

Ice cover calculations: The model can calculate onset, growth, and breakup of ice cover.

Selective withdrawal calculations: The model can calculate the vertical extent of the withdrawal zone based on outlet geometry, outflow, and density.

Time-varying boundary conditions: The model accepts a given set of time-varying inputs at the frequency they occur independent of other sets of time-varying inputs.

Outputs: The model allows the user considerable flexibility in the type and frequency of outputs. Output is available for the screen, hard copy, plotting, and restarts. The user can specify the desired output, as well as the timing and frequency of the output.

A6 Project/Task Description and Schedule

Tasks

Task 1

Develop a Quality Assurance Project Plan (QAPP) discussing the analytical/modeling approach will be submitted to EPA.

Task 2

Combine and update Washington and Idaho CE-QUAL-W2 models. This will be completed as follows:

- 1) Combine models and convert models to CE-QUAL-W2 Version 3.6 for 2001
- 2) Review and update boundary conditions if necessary
- 3) Re-run the model for calibration year 2001
- 4) Review the model calibration and prepare calibration report, draft and final, showing current model-data comparison.

Task 3

Preparation for a stakeholder meeting in Spokane and participation in the stakeholder meeting in Spokane. This first stakeholder meeting is scheduled for February 13, 2009. Elements of the QAPP will be presented and plans for the model update discussed. Issues raised by the stakeholder group during this meeting will then be addressed.

Task 4

Review potential scenario runs for technical clarity (not policy aspects), provide comments, and prepare a memorandum of recommendations. These recommendations would be for modeling accuracy and consistency between modeling steps.

Task 5

Preparation for a stakeholder meeting in Spokane and participation in the stakeholder meeting in Spokane. This second meeting is scheduled for March 25, 2009. A presentation of the updated calibration model will be made. Issues raised by the stakeholder group during this meeting will then be addressed.

Task 6

Run model scenarios. This will include the following steps:

- A. Set-up model for 8 scenarios
- B. Run 8 scenarios
- C. Post-process the modeling results
- D. Produce a draft and final report on scenarios

Task 7

Preparation for a stakeholder meeting in Spokane and participation in a stakeholder meeting in Spokane where modeling runs and scenario results will be presented. This meeting will occur in May 2009.

Schedule

The project schedule is shown in Table 1.

Table 1. Project Schedule.

ID	Task Name	Days	Start	End	20-Jan	27-Jan	3-Feb	10-Feb	17-Feb	24-Feb	3-Mar	10-Mar	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	
1	Quality Assurance Project Plan, Draft and Final	31	20-Jan	20-Feb																			
2	Combine and update Wa. and Id. CE-QUAL-W2 mode	51	2-Feb	25-Mar																			
a	Combine and convert models to v3.6	14	2-Feb	16-Feb																			
b	Review and update BC's as necessary	28	2-Feb	2-Mar																			
c	Rerun the model for year 2001	21	21-Feb	14-Mar																			
d	Review the model calibration and write report	25	21-Feb	18-Mar																			
3	Stakeholder meeting in Spokane #1, present plans for updated model	1	13-Feb	14-Feb																			
4	Review and comment on Potential Scenario Runs	60	13-Feb	14-Apr																			
5	Stakeholder meeting in Spokane #2, present updated model and scenario inputs	1	25-Mar	26-Mar																			
6	Run Model Scenarios	21	15-Apr	6-May																			
a	Set-up model for 8 scenarios	14	15-Apr	29-Apr																			
b	Run 8 scenarios	14	15-Apr	29-Apr																			
c	Post-process the modeling results	14	15-Apr	29-Apr																			
d	Report on Scenarios	7	29-Apr	6-May																			
7	Modeling workshop in Portland presenting	1	20-May	21-May																			

A7 Data Quality Objectives and Criteria for Model Inputs/Application

Data of known and documented quality are essential to the success of any water quality modeling study, which in turn generates data for use in various evaluations and to make decisions. Model setup, calibration, and validation for the task order covered under this QAPP will be accomplished using data available from other studies. The QA process for this study consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. To a large extent, the quality of a modeling study is determined by the expertise of the modeling and quality assessment teams. Project quality objectives and criteria for measurement data will be addressed in the context of Task 1 (see Section A6).

Input Data Criteria

Secondary data (for model input) will be downloaded electronically from various sources to reduce manual data entry whenever possible. When necessary, model inputs will be compiled from data collected by qualified sources including the EPA, Spokane Tribe, The City of Spokane, Spokane County, Avista Corporation, United States Geological Survey (USGS), US Army Corps of Engineers, and the Bureau of Reclamation. Secondary data will be organized into a standard model application database. A screening process will be used to scan through the database and flag data that are outside typical ranges for a given parameter; values outside typical ranges will not be used to develop model calibration data sets. The data used in the model, the time period from which the data were collected, and the quality requirements of the data will be described in the final report. If no quality requirements exist or if the quality of the secondary data cannot be determined, a disclaimer that indicates that the quality of the secondary data is unknown will be added. The wording of this disclaimer will be as follows: *The quality of the secondary data used in developing the TMDL could not be determined.*

Data Quality Objectives for Model Application

Data will be used in updating the model. QA reviews will be incorporated in these tasks and during database development. The use of quality data ensures that the system will be well described by the model and that model scenario predictions are realistic. The validity of the model will be determined by using model versus data graphical time series comparisons and error statistics, along with best of fit scatter plots.

Graphical and Statistical Applications

In order to illustrate the validity of the calibrated model graphical comparisons and error statistics will be shown in the final report. Model versus data time series plots will include the following parameters:

- water level
- flow rate
- water temperature
- dissolved oxygen
- soluble reactive phosphorus
- total phosphorus
- nitrite-nitrate nitrogen
- ammonia nitrogen
- chlorophyll a
- total nitrogen

- alkalinity
- pH
- total organic carbon
- ultimate CBOD
- conductivity
- total Kjeldahl nitrogen

Scatter plots of model prediction versus data will also be shown along with a best-fit linear regression line.

Calibration statistics of mean error, absolute mean error and root mean square error for the model predictions will also be listed in the final report.

The equation used for the mean error is:

$$\text{Mean_Error}(ME) = \frac{\sum_1^n (\text{model} - \text{data})}{n}$$

where 'n' is the number of observations, 'model' is the model predicted state variable and 'data' is the field data variable. The absolute mean error between model and data is defined as:

$$\text{Absolute_Mean_Error}(AME) = \frac{\sum_1^n \text{abs}(\text{model} - \text{data})}{n}$$

The root mean square error between the model and data is defined as:

$$\text{Root_Mean_Square_Error}(RMS) = \sqrt{\frac{\sum_1^n (\text{model} - \text{data})^2}{n}}$$

Graphical comparisons and statistics will also be used to determine the impact of the model scenarios.

A8 Documentation and Records

Portland State University will maintain all documentation and databases. Reports will be developed using Microsoft Word and the data bases through using Microsoft Excel/Access. When the project is completed project files including all reports, model files, and databases will be provided. Portland State University will back up and store all hard copy and electronic project information (including working files) in the Portland, OR for 5 years after the contract's expiration date.

Section B – Measurement and Data Acquisition

B1 Model Update

The Upper Spokane Idaho and Washington CE-QUAL-W2 models will be combined and updated to version 3.6. If necessary, boundary conditions will be updated. The calibration for the year 2001 will be checked. This process will include the following steps:

- 1) Combine models and convert models to CE-QUAL-W2 Version 3.6 for 2001
- 2) Review and update boundary conditions if necessary
- 3) Re-run the model for calibration year 2001
- 4) Review the model calibration and prepare calibration report, draft and final, showing current model-data comparison.

The CE-QUAL-W2 model includes a feature starting with version 3.5 (the Spokane River model will be converted to version 3.6) that allows for the variable stoichiometry of organic matter. Past versions of CE-QUAL-W2 models have used fixed stoichiometric constants for the ratios of nitrogen and phosphorus to organic matter. Eight new constituents are required to simulate the amount of nitrogen and phosphorus in labile dissolved organic matter (LDOM), refractory organic matter (RDOM), labile particulate organic matter (LPOM), and refractory particulate organic matter (RPOM). For each CBOD compartment two additional constituents are required to simulate nitrogen and phosphorus. Hence, all inputs of organic matter accumulate N and P according to the stoichiometry of the incoming organic matter.

Variable stoichiometry of sediments is done automatically within the version 3.6 CE-QUAL-W2 model. In addition to sediment phosphorus and sediment nitrogen, there is also a sediment carbon compartment. The sediment carbon stoichiometry is variable because organic matter, algae and epiphyton may have differing carbon stoichiometry. The decay rate of sediment in a model cell is the mass averaged decay rate of the LPOM, RPOM, and the CBOD groups.

If new data are available giving insight to model coefficient values, these data will be applied to the updated model.

The newer version of the CE-QUAL-W2 includes a fix to a modeling issue involving negative algae settling rates affecting nutrient release from the first-order sediment compartment.

Appendix A shows the changes in the CE-QUAL-W2 model since the original project using Version 3.1.

In addition, recent field studies in the Spokane River system will be evaluated to see if the 2001 model needs to be updated. Measurements of sediment oxygen demand and nutrient flux in Long Lake (Spokane Lake) will be considered. A recent groundwater study in the Spokane River basin will also be evaluated to make sure assumptions about groundwater measurements in the original model are still valid.

The model will also be checked to make sure that changes in flow along the Spokane River do not cause model segments to “dry-up”. Earlier, if changes were made in the flow rate in the system, a procedure had to be implemented to make sure that flow rates were balanced properly through the system of reservoirs and that they responded to changes in upstream flows.

B2 Non-Direct Measurements (Data Acquisition Requirements)

Non-direct measurements (also referred to as non-project-generated data) are data that were previously collected under a different effort outside this contract. Qualified sources will be used to develop model inputs and calibration data. Non-project-generated data may be obtained from published or unpublished sources. The published data will have some form of peer review. These data are generally examined by modelers as part of a data quality assessment. Databases that have not been published are also examined in light of a data quality assessment. Data provided by EPA, Spokane Tribe, City of Spokane, Spokane County, Avista Corporation, United States Geological Survey (USGS), US Army Corps of Engineers, and the Bureau of Reclamation, and other similar sources will be assumed to meet precision objectives established by those entities. If historical data are used, a written record of where the data were obtained and any information on their quality will be documented in the final report.

Model inputs will be developed from the following sources of meteorological data, bathymetric data, water quality data, stream flows, and water level data.

Bathymetric Data - USGS 10-meter Digital Elevation Models (DEMs).

<http://edc.usgs.gov/products/elevation/dem.html>

Flow and water level data - USGS, US Army Corps of Engineers, and Avista Corporation data.

<http://waterdata.usgs.gov/nwis>

<http://www.nwd-wc.usace.army.mil/perl/dataquery.pl>

Meteorological Data – Air temperature, dew point temperature, wind speed, wind direction, and short wave solar radiation data obtained from Bureau of Reclamation AgriMet Stations.

<http://www.usbr.gov/pn/agrimet/>

Water Quality Data – Sampling data obtained from the Washington Department of Ecology, City of Spokane, Spokane County including water temperature, dissolved oxygen, total dissolved solids, total suspended solids, nitrate, nitrite, total persulfate nitrogen (TPN), ammonia, total nitrogen, soluble reactive phosphorus, total organic carbon, ultimate CBOD, total phosphorus, pH and alkalinity measurements.

<http://www.ecy.wa.gov/>

B3 Data Management

Data used for calibration and to develop model inputs will be assembled using Microsoft Excel/Access database. Model input files and the database will be provided at the completion of the project. Model input files will include those used in the calibrated model and the scenarios.

Section C – Assessment and Oversight

C1 Assessment and Response Actions

The Project Manager / Technical Lead (Dr. Wells) has primary responsibility for monitoring the activities of this project and identifying or confirming any quality problems. These problems will also be brought to the attention of the Team QA Officer, who will initiate the corrective action system described above, document the nature of the problem, and ensure that the recommended corrective action is carried out.

C2 Reports to Management

The following deliverables will be submitted for quality assurance:

- Quality Assurance Plan (Draft submitted February 2, 2009)
- Draft and Final Model Report discussing data and state of model calibration (submitted mid-March, 2008)
- Draft and Final Report discussing scenarios (submitted early May, 2009)
- Conference calls as requested by EPA

Section D – Data Validation and Usability

D1 Data Review, Verification, and Validation

The data quality will be assessed by experienced professionals through a process of review and validation. Data entries, transmittals, and unit conversions will be reviewed for errors. A database will be used to compile and organize data, and will be scanned and potentially erroneous data flagged. If data values fall outside of normal ranges, these data values will be investigated and removed from the data base if found to be in error.

D2 Verification and Validation Methods

The review of data completeness and correctness will be overseen by the Project Manager / Technical Lead (Dr. Wells). Data will be imported into a Microsoft Access data base. Microsoft Excel will be used for unit conversions and data manipulation. To avoid data handling errors, data base values will be compared with original data. To facilitate data inspection the model input and calibration data will be plotted and included in the project report.

The model calibration will be reviewed. If necessary, calibration coefficients will be adjusted within ranges until model calibration error is within acceptable limits. The values of the model coefficients will be verified through comparison with literature values. Model predictions will be compared with data using time series plots, error statistics, and scatter plots. All plots and error statistics will be included in the modeling report.

Model predictions of the scenarios will be reviewed for reasonableness by using measured data, literature, and theory. Time series plots and statistics will be used to evaluate model predictions. Predictions will be evaluated on short (diurnal) and longer term (seasonal) time scales. If model predictions are unexpected, the model will be reviewed to insure that it is working properly. Source code for the model is readily available at the CE-QUAL-W2 website (<http://www.ce.pdx.edu/w2/>). Also available on the website is a user's manual, executables and examples. All statistics and plots used in scenario analysis will be included in the technical memorandum discussing scenario results.

D3 Reconciliation and User Requirements

The Project Manager / Technical Lead will ensure that data quality needs for the project are being met. Model predictions will be inspected to verify that results are useful and can be used to achieve project objectives.

References

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Appendix A Changes in CE-QUAL-W2 between Version 3.1 and 3.6

The original Spokane River model used CE-QUAL-W2 Version 3.1. Since that time the model has undergone multiple bug fixes and Version updates. Released versions included Version 3.2, 3.5 and 3.6. The changes to the CE-QUAL-W2 model as a result of these updates are shown below.

Version 3.2. Version 3.2 is a result of additional improvements to the model. These new capabilities include:

1. Internal code rewrite to reduce code size, simplify code maintenance, and improve model execution speed
2. New screen display during model run-time. The new screen display allows for controlling the processor usage, examining output variables, and stopping, starting and restarting a model run on the fly. This allows the model user to stop a code, then make changes in the control file or any input file, and then restart the model at the point that it was stopped.
3. Addition of a new algorithm to estimate suspended solids resuspension as a result of wind-wave action.
4. Reorganization of the graph.npt file to allow more output control formatting possibilities.
5. New turbulent kinetic energy-turbulent dissipation turbulence closure model was added to the model.

Version 3.5. Version 3.5 is a result of significant enhancements to the model. These new capabilities include:

1. Addition of the macrophyte model of Berger and Wells (in-review) with a user-defined # of species
2. Addition of a zooplankton model with a user-defined # of species based on an updated version of the CE-QUAL-R1 model (Environmental Laboratory, 1995)
3. Addition of a new focusing or settling velocity for sediments that accumulate in the first order sediment model. In earlier versions, sediment focusing occurred at the velocity given for POM. In this version, a user can specify that focusing velocity. This means that sediments can still migrate toward the bottom of the channel over time even after they have hit the sidewalls of the channel.
4. User-defined time-variable input of P and N associated with organic matter inputs. In earlier versions, the P or N associated with organic matter was based on a static stoichiometric coefficient specified in the control file. Now, the user provides in the input files the dynamic P and N associated with organic matter inputs from tributaries or inflows. This is essentially allowing for variable stoichiometry in the input boundary conditions.
5. Based on the above refinement, the organic matter fractions within the model now have variable stoichiometry for P and N. This preserves P and N mass balances. The stoichiometry given in the input files is merely the initial value of the C-N-P stoichiometry of POM and DOM compartments. Hence, organic P and organic N are tracked correctly in the code.
6. The first order sediment model also tracks C-N-P correctly and has a dynamic stoichiometry as it accumulates organic matter in the sediment. Prior versions of W2 had a user-defined value of fixed stoichiometry for the 1st order sediment model. Also, instead

of a fixed decay rate for the sediments, the decay rate is dynamic based on the decay rates of the accumulated organic material. A mass weighted average is used.

7. CBOD groups now have a user-defined settling velocity. Hence, the user can define organic matter groups as particulate and dissolved based on specification of the settling velocity. As in prior versions, CBOD has associated stoichiometry and if there is settling, it will accumulate in the 1st order sediment compartment.
8. A Monod formulation was implemented for the initiation of anaerobic processes and reduction of aerobic processes. In earlier model versions there was a specified oxygen concentration that acted like a step function turning these processes on or off.

Version 3.6. This version is file compatible with version 3.5. Hence no changes need to be made to any input files. Even though there are some new features in the input files, these are not required for users of V3.5 and can be kept blank. The primary change is allowing the code to run on multiple processors. The following changes have been made in the code from V3.5 to V3.6:

1. The code has been rewritten into smaller subroutines to allow better code compilation and optimization.
2. The code has been revised with the goal of improving the computational speed. This new compiled code using Intel Visual Fortran 10 should be faster on a single processor than the V3.5 code compiled on a PC with CVF 6.6.
3. The code now has OPENMP commands embedded to allow for limited parallelization of some of the routines. Current tests show that going from 1 processor to 2 can result in up to 20-40% speed improvement.
4. The TKE algorithm has been updated with new algorithms that match experimental tank data for kinetic energy and dissipation. This is based on a Master's degree project by Sam Gould at Portland State University. A new user option is the TKE1 algorithm, in addition to the legacy algorithm TKE.
5. The roughness height of the water for correction of the vertical velocity wind profile is now a user-defined input, z_0 . Prior to this the model had hardwired the value of $z_0=0.003$ m for wind speed correction at 2m (for evaporation where wind height at 2 m is typical) and $z_0=0.01$ m for wind at 10 m (for shear stress calculations where wind height of 10 m is typical). For consistency, both conversions now use the same value of roughness height. If the user does not specify the value of z_0 (for example if he/she leaves the spaces blank for z_0 using a V3.5 control file), the code uses 0.001 m.
6. The Windows user interface no longer uses Array Viewer. The dialog box and PC executable no longer require installation of Array Viewer (which is now obsolete) nor do they need the Array Viewer DLL. The Dialog box has some minor improvements: model run directory displayed and a progress bar.
7. Fixed error with Algae/chlorophyll a ratio in user manual and fixed pre-processor. The earlier language in the user manual discussed an Algae/Chlorophyll a ratio but presented

information that was the ratio of chlorophyll a/algae – this has been revised and fixed in User Manual and in preprocessor.

8. Spreadsheet output: in earlier versions put in an alphanumeric character as a space for the spreadsheet to preserve the formatting. This was changed to a default value of -99 to facilitate numeric data processing. Also, the “-Depth” output value was changed to just “Depth” since modern plotting programs can reverse an axis.
9. Preprocessor improvements. Added variable checks for new parameters, fixed bugs, new check for wsc.npt file (not checked in earlier versions).
10. For the generic constituent, added temperature dependence on 0th order decay and fixed errors in User Manual for units of zero order decay coefficient.
11. Added the kinetic flux rates to the TSR file output for easier analysis using a spreadsheet of the flux terms for specific locations in the modeled system.
12. Revised the computation of the drag coefficient for low wind speeds so that the model now agrees better with theory in this wind speed range.
13. The light extinction coefficient (in m^{-1}) is now included as an output variable in the TSR opt file. Because the model internally computes the light extinction coefficient based on water, SS, POM, algae, zooplankton, and macrophytes, this is an important parameter understanding the internal light transmission predicted by the model. This variable replaces the equilibrium temperature as an output variable.
14. A new option for output is in the format required for TECPLOT. For TECPLOT animation there is only a flag in the CPL output line. This allows for easy model animation of the variables U, W, T, RHO, and all active constituents at the frequency specified by the CPL file as a function of distance and elevation.
15. A new variable for determining the fraction of NO₃-N that is diffused into the sediments that becomes organic matter, or SED-N was introduced.
16. In V3.5 the model computed an average decay coefficient of the sediments based on what was deposited. The user now has the option to dynamically compute that decay rate or to have it fixed and controlled by the model user. A new variable was introduced called DYNSEDK which is either ON/OFF to allow or not allow dynamic computation of the sediment decay rate.
17. Added Kinetic flux output that sums up fluxes for all cells of a waterbody at the output frequency specified in the kinetic flux output. The output filenames are called “kflux_jw#.opt” where # is the waterbody number. All active fluxes are summed for the waterbody. This is an important overall diagnostic tool to evaluate the important fluxes in the waterbody over time. Instantaneous fluxes are output in the TSR file for individual cells and a series of fluxes at given segments are shown in the Flux output file which is similar in format as the SNP file. This new file is easy to import into a spreadsheet for analysis.
18. The selective withdrawal algorithm computation was adjused to more closely follow the Corps’ model code SELECT (based on personal communication with Gary Hauser, 2008). The variable DLRHOMAX is used to compute the relative velocity profile. In V3.5 and earlier, this

variable was the maximum for the entire profile above and below the outlet, i.e., $DLRHOMAX = \text{MAX}(DLRHOT, DLRHOB)$. In V3.6 and later, DLRHOT is used above the outlet and DLRHOB is used below the outlet.