August 2007 Spokane River Model Simulations

Chris Berger

Robert Annear

And

Scott A. Wells

Maseeh College of Engineering and Computer Science
Department of Civil and Environmental Engineering
Portland State University
Portland, Oregon 97201-0751

DRAFT

Prepared for Washington Department of Ecology

August 2007

Spokane River Total Maximum Daily Load (TMDL) scenarios were simulated using the CE-QUAL-W2 model developed for the Washington Department of Ecology by Portland State University (Berger et al., 2003).

The scenarios were run with varying dissolved phosphorus inputs for Washington tributaries to determine the amount of additional phosphorus that would reduce Long Lake dissolved oxygen by 0.2 mg/l with respect to background conditions. Phosphorus rather than ammonia was varied because it has more of a significant impact on algal production. Background conditions are defined as the water quality without human caused pollution sources. The adjusted Washington tributaries were Hangman Creek, Coulee Creek, and the Little Spokane River. Input files at the upstream boundary condition, located at the Washington-Idaho state line, were provided by EPA and used for all the simulations except for the calibration simulation. These input files were the output of the upstream model that was developed for the Idaho section of the Spokane River. The Idaho simulation included point source loads corresponding to the proposed Idaho discharge limits, and this simulation is referred to as the "LIMIT" scenario.

The Washington scenarios were listed in Table 1. The scenarios had Washington point source nutrient and CBOD loadings set to groundwater conditions. Scenario A had tributary inputs at background levels. Scenario B had CBOD concentrations at 2001 levels and dissolved phosphorus at background levels. For Scenario C the CBOD concentrations remained at 2001 levels, but dissolved phosphorus was increased 2.5 times from background levels. Scenario D was the 2001 calibration run.

Table 1. Descriptions of model scenarios and their tributary loads.

Scenario	Description of tributary loads	Dissolved P	CBOD	Upstream Boundary Condition
A	Background inputs	Background	Background	EPA "limit" run for Idaho
B	CBOD at 2001 levels, dissolved P at background levels	Background	2001 levels	EPA "limit" run for Idaho
C	CBOD at 2001 levels, dissolved P at 2.5 times background levels	2.5X background concentrations	2001 levels	EPA "limit" run for Idaho
D	2001 Calibration Run	2001 levels	2001 levels	Data

For each scenario, the model cell weighted average dissolved oxygen concentration for the model segment adjacent to the Lake Spokane dam (segment 188) was calculated, selecting only cells that had values below 8.0 mg/l. At a time step of 0.02 days, the algorithm would scan the model cells adjacent to Lake Spokane dam for concentrations less than 8.0 mg/l. For each time step, the concentrations of cells satisfying the "less than 8.0 mg/l concentration" criterion would be averaged. To permit comparisons between simulations having slightly different hydrodynamics, the model predictions were smoothed for each scenario by calculating the running average of the concentrations using a window of one-fifth of a day. The difference in the "smoothed" cell weighted

concentrations of the scenarios relative to the background conditions scenario were calculated and plotted in Figure 1. Increasing the dissolved phosphorus 2.5 times in tributaries reduces the cell weighted average of the dissolved oxygen concentrations at the dam by approximately 0.2 mg/l, compared to background conditions.

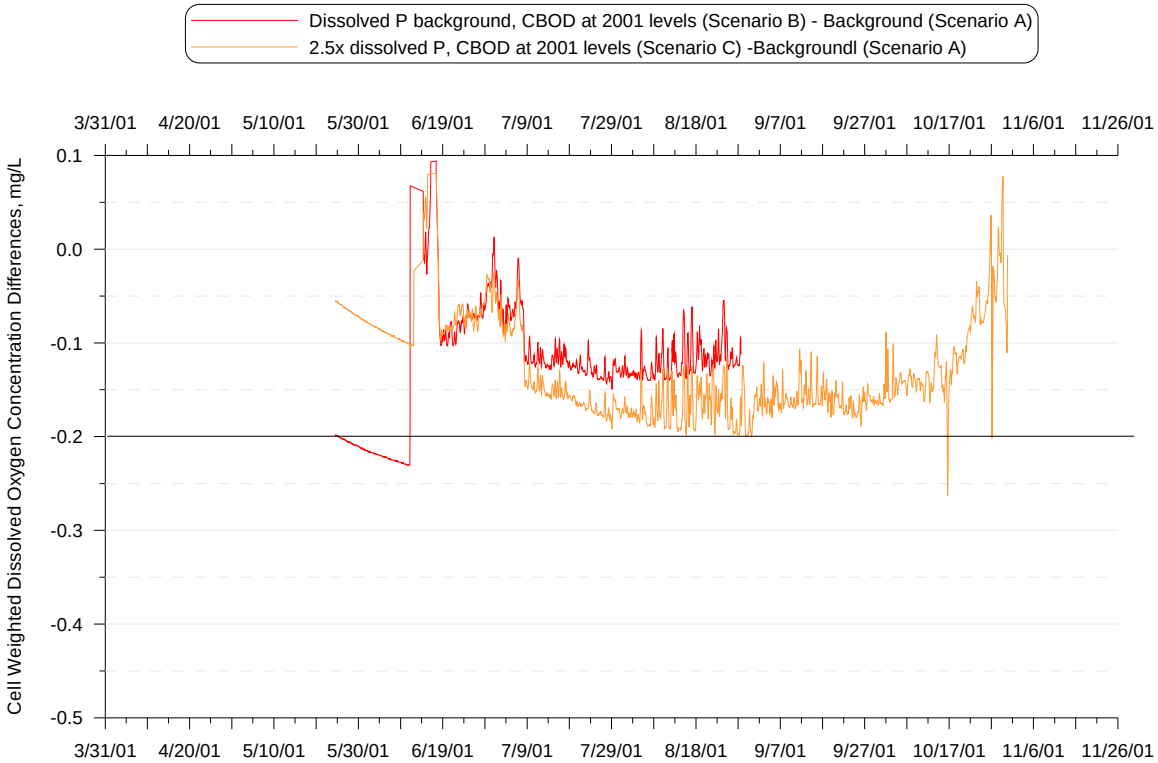

Figure 1. Plot of cell weighted dissolved oxygen differences for model segment adjacent to dam (segment 188) and considering only cell concentrations less than 8.0 mg/l. The linear nature of the plots prior to June 19 is due to lack of variation and the low number of model cells being used in the calculation. The dissolved oxygen differences were not plotted before May 20 because there were not any model cells predicting concentrations less than 8.0 mg/l. The dynamic fluctuation occurring after October 15th were caused by differences in the hydrodynamics in the model runs. The different nutrient loadings in the scenarios caused differing amounts algae growth, which slightly affected temperature predictions by changing the water transparency. The different temperature predictions affected the timing of turnover events during Fall, leading to the fluctuations in the predicted dissolved oxygen differences.

The April/May tributary phosphorus loadings for the current conditions scenario, the background conditions scenario, and 2.5X background P concentration in tributaries scenario were shown in Table 2. The June through October and the April through October tributary phosphorus loadings for these scenarios were shown in Table 3 and Table 4, respectively. For the May/April period, the 2.5X background P in tributaries scenario corresponds to a 24% reduction of phosphorus loadings from 2001 levels. The reduction in phosphorus loadings for the June through October period was 6% and for the April through October period was 16%.

Table 2. April/May phosphorus loadings of tributaries for current conditions (2001) scenario, background conditions scenario, and 2.5X background P concentration scenario. Loadings from the current conditions scenario have to be reduced 24% to be equivalent to the P loadings of the 2.5X background P concentration scenario.

Average pounds/day of TP				
	Current 2001 Scenario D	Background Scenario A	TMDL, or 2.5x P concentration Scenario C	Percent Reduction from 2001 levels
Hangman	82.58	18.96	50.61	39%
Coulee	14.02	3.20	8.54	39%
Little Spokane	131.47	59.30	114.62	13%
Total	228.07	81.46	173.77	24%

Table 3. June through October phosphorus loadings of tributaries for current conditions (2001) scenario, background conditions scenario, and 2.5X background P concentration scenario. Loadings from the current conditions scenario have to be reduced 6% to be equivalent to the P loadings of the 2.5X background P concentration scenario.

Average pounds/day of TP				
	Current 2001 Scenario D	Background Scenario A	TMDL, or 2.5x P concentration Scenario C	Percent Reduction from 2001 levels
Hangman	4.25	1.32	3.31	22%
Coulee	1.05	0.34	0.84	20%
Little Spokane	58.21	36.04	55.75	4%
Total	63.51	37.7	59.9	6%

Table 4. April through October phosphorus loadings of tributaries for current conditions (2001) scenario, background conditions scenario, and 2.5X background P concentration scenario. Loadings from the current conditions scenario have to be reduced 16% to be equivalent to the P loadings of the 2.5X background P concentration scenario.

Average pounds/day of TP				
	Current 2001 Scenario D	Background Scenario A	TMDL, or 2.5x P concentration Scenario C	Percent Reduction from 2001 levels
Hangman	26.63	6.36	16.82	37%
Coulee	4.76	1.16	3.04	36%
Little Spokane	79.14	42.69	72.57	8%
Total	110.53	50.21	92.43	16%

References:

Berger, C.J., R.L. Annear, S.A. Wells, and T. Cole, 2003. "Upper Spokane River Model: Model Calibration 2001." Technical Report EWR-01-03. Department of Civil Engineering, Portland State University, Portland, OR.

Merrill, K. and B. Cusimano (2004). " Total maximum daily load to restore and maintain dissolved oxygen in the Spokane River and Lake Spokane (Long Lake), DRAFT." Water Quality Program, Washington State Department of Ecology, Olympia, Washington.

Appendix A – Adjustment of Washington Model Calibration

The flow input file for Hangman Creek was updated from a file that used estimated flows to a file using data. The new flow file, which had greater flows, resulted in the need to update the model calibration. Changes to modeling coefficients are summarized in Table 5.

Table 5. Modeling coefficients adjusted.

Coefficient	Description	Change
SEDK	first order sediment decay rate	0.10 d^{-1} to 0.08 d^{-1}
LDOMDK	labile dissolved organic matter decay rate	0.10 d^{-1} to 0.08 d^{-1}
SOD	Zero order sediment oxygen demand (SOD)	Segments 130-153 (Nine Mile Rersevoir): 0.5 to 0.3 g O_2 m^{-2} d^{-1} Segments 154-162 (upstream Long Lake): 0.6 to 0.1 g O_2 m^{-2} d^{-1} Segments 163-177 (middle Long Lake): 0.6 to 0.3 g O_2 m^{-2} d^{-1}

The new model error statistics for dissolved oxygen predictions are listed in Table 6. Figure 2 through Figure 7 show model-data comparison of dissolved oxygen profiles in Long Lake.

Table 6. Dissolved oxygen profile error statistics, 2001

Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	1.04	1.26
LL1	2	1.52	1.67
LL2	2	1.17	1.38
LL3	2	0.69	0.86
LL4	2	1.10	1.29
LL5	2	1.11	1.24
Avg.		1.11	1.28

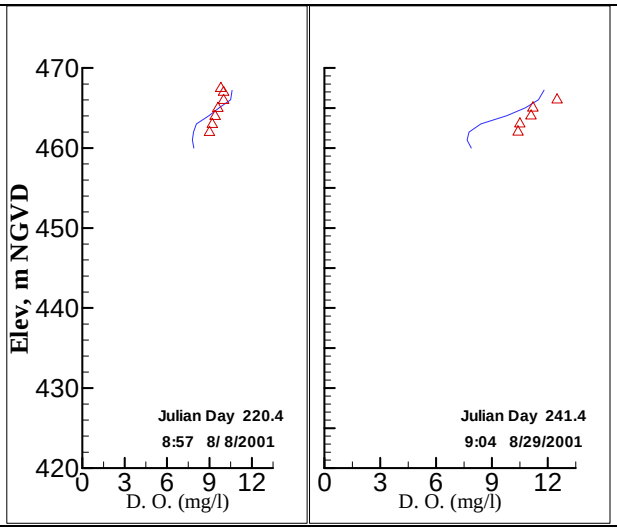

Figure 2. Dissolved oxygen predictions and data for station LL5 (segment 157).

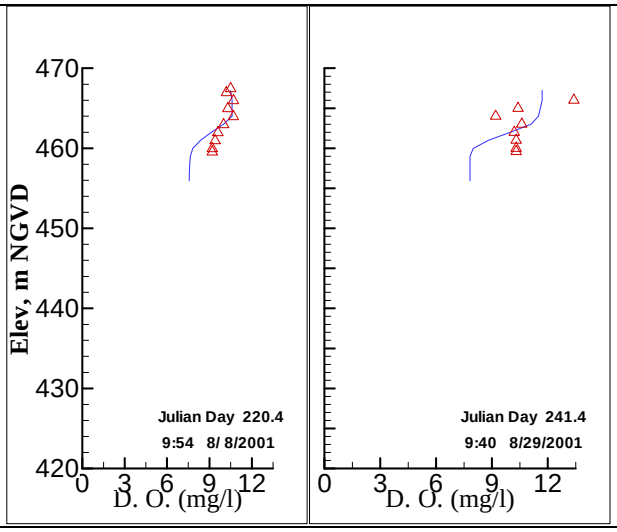

Figure 3. Dissolved oxygen predictions and data for station LL4 (segment 161).

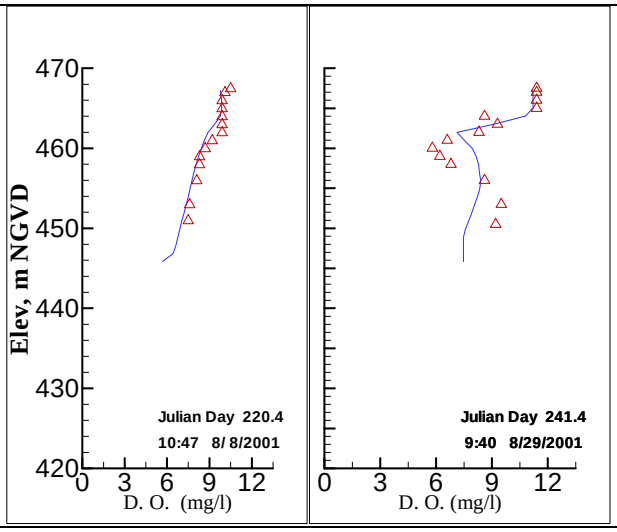

Figure 4. Dissolved oxygen predictions and data for station LL3 (segment 168).

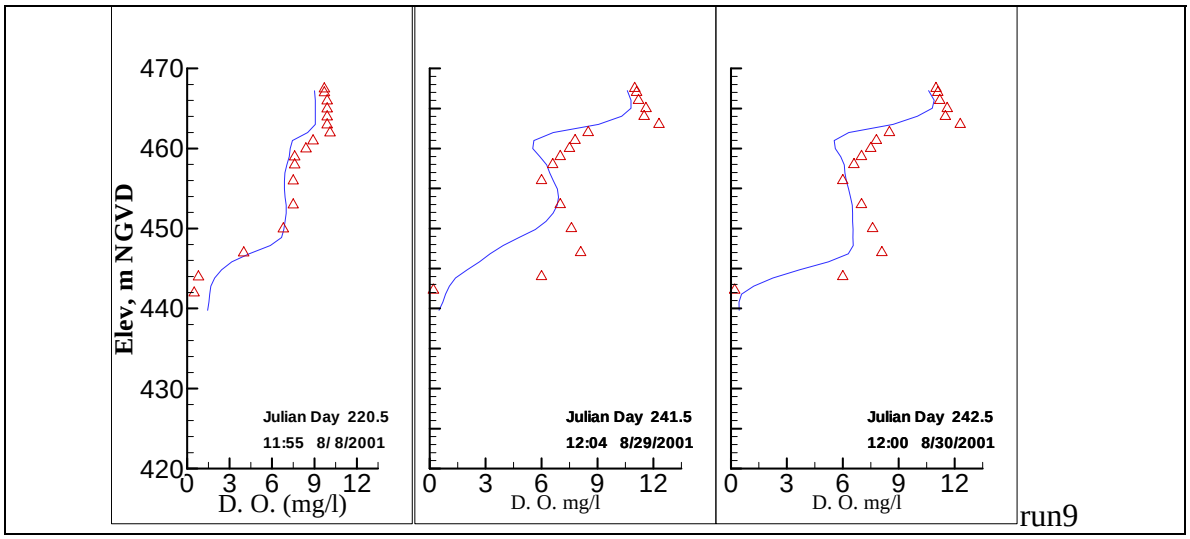

Figure 5. Dissolved oxygen predictions and data for station LL2 (segment 174).

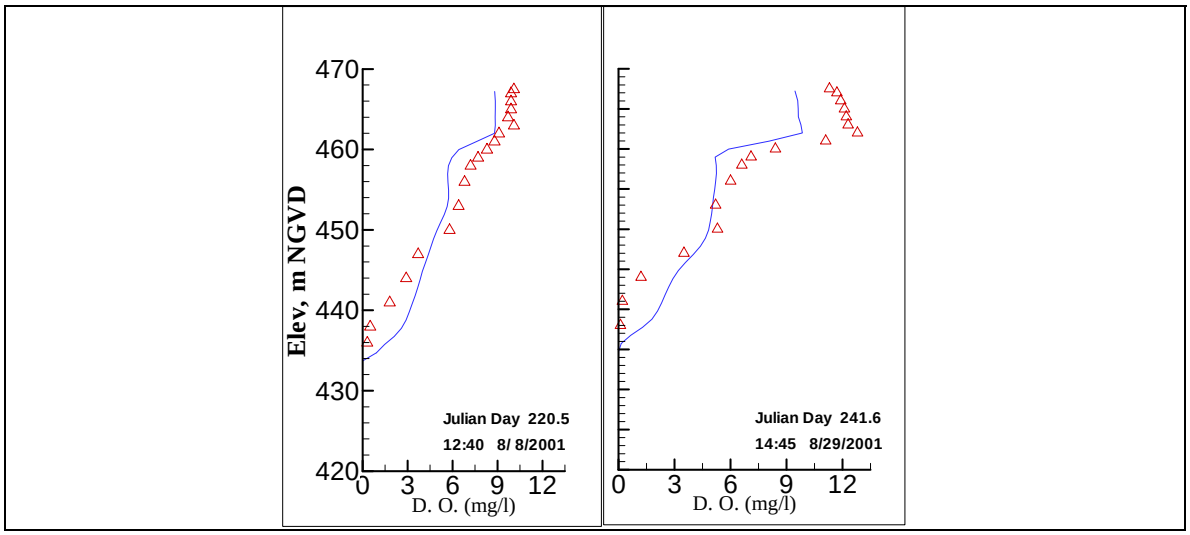

Figure 6. Dissolved oxygen predictions and data for station LL1 (segment 180).

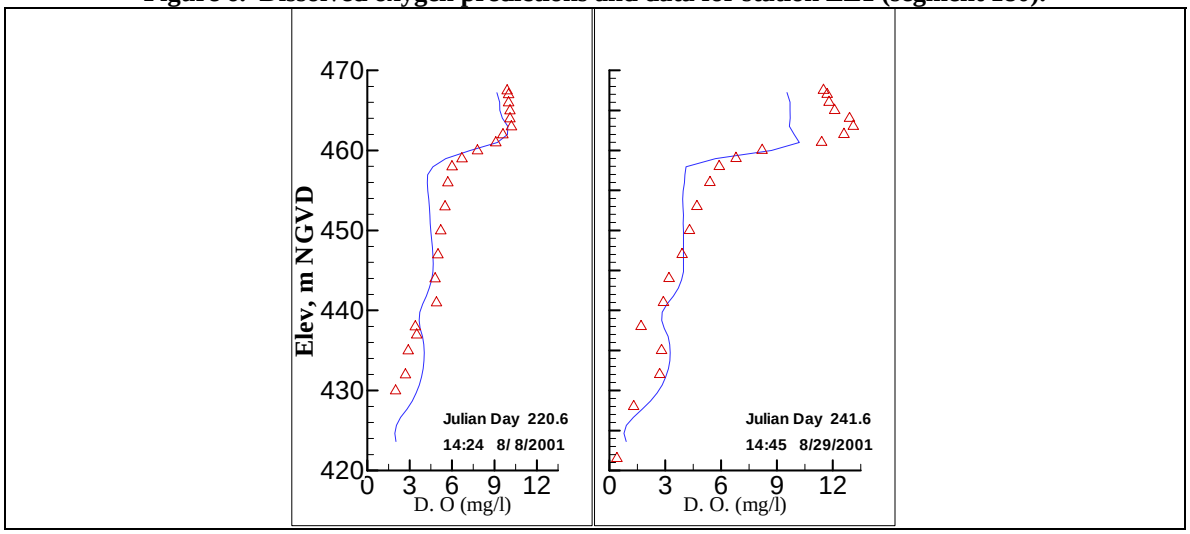

Figure 7. Dissolved oxygen predictions and data for station LL0 (segment 187).

Appendix B – Calculation of Concentrations and Loads

The monthly concentrations used in the TMDL worksheets calculated by PSU were determined by totaling the constituent mass flowing out of a tributary or passing a specific segment and dividing by the corresponding monthly total volume of water. Model input files (for the tributaries and state line) or output files (Nine mile Dam) were read at a arbitrary time interval of 0.05 days ($\Delta t = 0.05$) and the constituent concentration C was multiplied by the instantaneous flow rate Q_i to determine the total mass for that time interval. Thus the total mass M_i for time step i was calculated using

$$M_i = Q_i * C * \Delta t$$

The monthly total mass M was then determined by

$$M = \sum_{i=1}^{n} M_i = \sum_{i=1}^{n} Q_i * C * \Delta t$$

where n was the total number of times steps in a month.

Likewise, the total water volume V was calculated with

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} Q_i * \Delta t$$

Using the monthly total mass and the total monthly water volume, the monthly average concentration was then calculated with

$$C = \frac{M}{V}$$

Appendix C – Linking Idaho and Washington Models

The phosphorus (P) stoichiometry (the ratio of P mass to total mass), nitrogen (N) stoichiometry, and carbon stoichiometry (C) of the organic matter compartments of the Idaho and Washington Spokane River models are different. For example, the Idaho model uses a P stoichiometry coefficient for organic matter of 0.001 and the Washington model has a value of 0.005. In CE-QUAL-W2 organic matter is divided into labile dissolved organic matter (LDOM), labile particulate organic matter (LPOM), refractory dissolved organic matter (RDOM), and refractory particulate organic matter (RPOM) compartments. Since the fraction of P, N, or C in organic matter differs between the 2 models, the organic matter concentrations predicted at the downstream end of the Idaho model cannot be input into the Washington model's corresponding organic matter compartments without violating the conservation of mass. Table 7 lists the stoichiometry coefficient values of the two models for all 4 of organic matter compartments simulated in CE-QUAL-W2.

Table 7. Phosphorus, nitrogen, and carbon stoichiometric values for the organic matter compartments in the Idaho and Washington Spokane River models. In the CE-QUAL-W2 control file the phosphorus stoichiometric variable is ORGP, the nitrogen stoichiometry variable is ORGN, and the carbon stoichiometry variable is ORGC.

Organic Matter Compartment	Phosphorus Stoichiometry (ORGP)		Nitrogen Stoichiometry (ORGN)		Carbon Stoichiometry (ORGC)	
	Idaho	Washington	Idaho	Washington	Idaho	Washington
Labile Dissolved Organic Matter (LDOM)	0.001	0.005	0.010	0.08	0.60	0.45
Refractory Dissolved Organic Matter (RDOM)	0.001	0.005	0.010	0.08	0.60	0.45
Labile Particulate Organic Matter (LPOM)	0.001	0.005	0.010	0.08	0.60	0.45
Refactory Particulate Organic Matter (LPOM)	0.001	0.005	0.010	0.08	0.60	0.45

As a work around, four new CBOD compartments are being created in the Washington model, which brings the total number of CBOD compartments in the model to 14. These four additional compartments will simulate the organic matter originating from the Idaho models organic matter compartments (LDOM, RDOM, LPOM and RPOM). To do this, the organic matter concentrations have to be converted to carbonaceous biochemical oxygen demand concentration. In the Spokane model it is assumed that the stoichiometric requirements for organic matter decay are 1.4 g O_2 per 1 g organic matter. To convert organic matter concentrations into CBOD concentrations the following expression is used:

$$CBOD\ concentration = OM\ concentration \times 1.4$$

Also, in order to conserve P, N, and C mass in the conversion the stoichiometric ratios of the new CBOD compartments must be calculated using:

$$(P, N\ or\ C\ stoichiometry\ for\ CBOD\ decay) = (stoichiometric\ equivalent\ btw.\ OM\ and\ P, N, or\ C)/1.4$$

The CBOD compartments in the Washington model and their sources are listed in Table 8. CBOD compartments #11 through #14 correspond to the four Idaho organic matter compartments.

Table 8. The CBOD compartments in the Washington model. Compartments #11 through #14 correspond to the Idaho models organic matter compartments. The stoichiometric ratios for each compartment are also listed.

CBOD compartment # in Washington model	Corresponding Source	P stoichiometry for CBOD decay (BODP)	N stoichiometry for CBOD decay (BODN)	C stoichiometry for CBOD decay (BODC)
1	Liberty Lake	0.020	0.08	0.45
2	Kaiser Aluminum	0.002	0.08	0.45
3	Inland Empire Paper	0.002	0.08	0.45
4	Spokane WWTP	0.016	0.08	0.45
5	Organic matter from Washington Tributaries	0.011	0.08	0.45
6	Coeur D'Alene WWTP	0.00047	0.08	0.45
7	Hayden POTW	0.00496	0.08	0.45
8	Post Falls STP	0.00041	0.08	0.45
9	Lake Coeur D'Alene CBOD	0.003	0.08	0.45
10	Hayden POTW summer discharge	0.0001	0.08	0.45
11	Idaho Labile Dissolved Organic Matter (LDOM)	0.000714	0.00714	0.429
12	Idaho Refractory Dissolved Organic Matter (RDOM)	0.000714	0.00714	0.429
13	Idaho Labile Particulate Organic Matter (LPOM)	0.000714	0.00714	0.429
14	Idaho Refractory Particulate Organic Matter (LPOM)	0.000714	0.00714	0.429

Some additional comments:

- To adequately simulate the settling of particulate organic matter in the CBOD compartments a settling term for CBOD was added into version 3.1 CE-QUAL-W2.
- Organic matter originating from Lake Coeur D'Alene has a faster decaying component simulated as CBOD compartment #9 (in both Idaho and Washington models), and a slower decaying component (simulated as refractory DOM in the Idaho model, and as CBOD compartment #12 in the Washington model).
- The organic matter compartments in the Washington model only simulate organic matter originating from algae mortality. Organic matter from dischargers and tributaries are accounted for with corresponding CBOD compartments.