# Appendix K.2 GEMSS code corrections by Ecology

Ecology conducted a review of the Fortran code for the WQCBM, GAM, and WQADD water quality modules in GEMSS prior to the review that was presented in Appendix K.1 by Bob Ambrose. All of the coding revisions that were conducted by Ecology were also reviewed by Bob Ambrose in his review. This appendix presents the coding errors that were discovered by Ecology and corrected by ERM.

### Changes made after Ecology’s 2008 draft report

**Provision for optional use of legacy methods**

In order to preserve some of the original methods in the model code for legacy applications, and also provide a corrected coding option for this project and future Ecology projects, a new variable was introduced in the WQCBM and GAM modules called UseLOTTMethod. If UseLOTTMethod = 1, then the original method would be used for a particular process. If UseLOTTMethod = 0 then the corrected method would be used. For this project and all future Ecology projects, we set UseLOTTMethod = 0 to use the corrected methods. Therefore, sections of the code that would be executed if UseLOTTMethod = 1 are ignored during model execution for Ecology’s applications and can be ignored by external reviewers for the purpose of reviewing the model code that is used for Ecology’s project. Ecology does not recommend use of the legacy methods due to numerous significant errors.

**Dinoflagellate dark uptake of nutrients and conservation of mass of N and P**

The original code represented the respiration term (dr\_f) for the dinoflagellate variable (I\_DFP) as a nutrient source term during periods of photosynthesis, and nutrient sink term at night for the nutrient variables (ammonia (I\_NH3) and inorganic P (I\_PO4)). This process provided dinoflagellates with the ability to take up nutrients at night (“dark uptake” of nutrients). The main problem with this formulation was that the DFP variable (and all other phytoplankton variables in WQCBM and GAM) is assumed to have constant stoichiometric ratios of C:N:P that are specified as model input parameters.

The assumption of constant stoichiometry requires that any nutrient source or sink term associated with the kinetics of DFP must be associated with a corresponding proportional increase or decrease in the biomass of DFP, otherwise the total mass of nutrients in the system would not be conserved. For example, if respiration of DFP at night reduces the concentration of ammonia and phosphate, but there is not a corresponding increase in the N and P content of DFP biomass, then the dark uptake of nutrients represents a leak of the total mass of nutrients from the system which would violate conservation of mass. This problem was compounded by the treatment of respiration as a loss term for biomass of DFP (and the proportional loss of stored N and P contained in that biomass) at the same time that it was treated as a loss term for the nutrient variables with dark uptake. Both of these processes contributed to a leak of N and P from the system because the dark uptake of N and P did not go into a corresponding increase in the biomass of N and P, and the simultaneous loss of biomass of N and P did not go into the pools of N and P in the nutrient variables.

The first attempt to fix this problem involved changing the respiration term for DFP to a growth term for DFP at night. In other words, during the daytime the respiration of DFP is a source term for nutrients and a corresponding proportional sink term for the biomass of DFP, but at night the respiration of DFP is a sink term for nutrients and a corresponding proportional source term for the biomass of DFP, as follows (lines 607-611 in WQCBM).

If(xri\_f.gt.0.0) Then

p42b = - dr\_f\*c(n,k,I\_DFP) !daytime respiration is a loss term for Dinos

Else

p42b = dr\_f\*c(n,k,I\_DFP) !dark respiration is a growth term for Dinos

EndIf

Where xri\_f is the light limitation factor for growth of DFP (varies between 0 and 1 with 0 representing complete cessation of growth due to lack of light at night, and 1 representing no inhibition of growth due to light.

This change had the advantage of solving the problem of conservation of mass of N and P. However it had the disadvantage of unrealistic representation of the actual metabolism of dinoflagellates, and it also does not account for the source of C that would be assimilated into the biomass of DFP at night. Therefore this modification was abandoned.

The best fix for the problem of conservation of mass with dark uptake of nutrients was to remove this mechanism from the model and always treat respiration as a loss term for the biomass of DFP. In other words, respiration is always treated as a source term for nutrients and a corresponding proportional loss term for the biomass of DFP to maintain conservation of mass. This was accomplished in the Fortran code in WQCBM by changing the conditional in line 607 from “gt” to “ge” as follows such that the second condition in the If statement would never occur because the term xri\_f is never less than zero:

If(xri\_f.ge.0.0) Then

p42b = - dr\_f\*c(n,k,I\_DFP) !daytime respiration is a loss term for Dinos

Else

p42b = dr\_f\*c(n,k,I\_DFP) !dark respiration is a growth term for Dinos

EndIf

The same change was applied to the derivatives for nutrients to always treat respiration as a source term in lines 524-528 and lines 577-581, where xri\_f is never less than zero.

**Light extinction and PAR**

The original LOTT method was discovered to contain significant errors related to light limitation calculation:

* total chlorophyll a was not correctly summed across phytoplankton groups
* light extinction was not correctly calculated from total chlorophyll a
* the integrated average light intensity in each layer was not correctly calculated
* total solar radiation was assumed to represent photosynthetically active radiation
* incorrect unit conversions were used to convert solar radiation from W/m^2 to langleys/day
* the formula for the Steele function for light limitation was incorrect.

The corrected calculations for each grid cell layer are documented in lines 384-432 and 460-486 of WQCBM.f90

The revised equation for the light extinction (Ke, m^-1) in the WQCBM module is the following formula:

Ke = Ke\_a + Ke\_b \* Chla ^ Ke\_c

Where Chla is the total phytoplankton chlorophyll a concentration (ug/L) in the water column summed across all phytoplankton groups used in the WQCBM and GAM modules, and Ke\_a, Ke\_b, and Ke\_c are empirical model input parameters. The parameter values Ke\_a=0.336, Ke\_b=0.0365, and Ke\_c=0.64 were used as model inputs in this application estimated based on regression of observed extinction and phytoplankton chlorophyll a data from South Puget Sound.

### Earlier model changes through Ecology’s 2008 draft report

From 2003 through 2007, Ecology contracted with ERM to perform the following tasks:

* Conversion of the 1997 LOTT model to the latest version of GEMSS.
* Verification of goodness-of-fit relative to the 1997 calibration.
* Capitol Lake setup in GEMSS, linkage with Budd Inlet, and testing.
* Incorporation of a more recent data set (2000-2001 Miller Brewing Company study of Capitol Lake).
* Conduct a workshop on the GEMSS application for Ecology staff.
* Calibration assistance and technical support.

The following additional tasks were performed by ERM:

1. Updated the existing Budd Inlet model setup to include the combined Budd Inlet and Capitol Lake grid connected by the outlet structure at the dam.
2. Calibrated the flow exchange of the combined Capitol Lake/Budd Inlet GEMSS model application to recent data collected during 2003-2004 by Ecology and Thurston County. The simulation period was May 18, 2004 – September 30, 2004.
3. Calibrated temperature, DO, and other water quality constituents of the combined Capitol Lake/Budd Inlet GEMSS model application to recent data collected during 2003-2004 by Ecology and Thurston County. The simulation period was May 18, 2004 – September 30, 2004.
4. Confirmed flow exchange, temperature, DO, and other water quality constituents of the combined Capitol Lake/Budd Inlet model application with recent data collected during 2000-2001 by CH2MHill (2001) and Thurston County. The simulation period was April 25, 2001 – June 13, 2001.
5. Performed model scenario runs and comparisons for a total of eight scenarios. Four scenarios included the dam and four scenarios assumed that dam was not present and that Capitol Lake functioned as an estuary.
6. Documented and delivered of the work products of bullets 1 through 5. A memo report was provided by ERM.

The project was scoped originally to utilize the calibrated and accepted model of Budd Inlet from the Budd Inlet Scientific Study, given the significant resources invested in this model calibration and extensive review by multiple entities. Because that model considered Capitol Lake as a boundary condition, the model domain was extended south to encompass Capitol Lake. However, no recalibration of Budd Inlet was planned.

In 2006, ERM provided the latest calibrated model of Budd Inlet to Ecology along with a comparison to the previous model outputs (Kolluru, 2006). ERM also provided a combined calibrated model of Budd Inlet/Capitol Lake in January 2008.

In the course of review of the calibrated Budd Inlet/Capitol Lake model, the source codes for the Water Quality Carbon-Based Module (WQCBM) were reviewed. The following issues with WQCBM were noted and later corrected by ERM:

1. The increase in zooplankton biomass due to grazing was not included in any of the mass balance equations for particulate organic phosphorus, nitrogen, and carbon. This inclusion was necessary for mass balance to be correct.
2. The particulate organic carbon was expressed in units of oxygen rather than carbon.
3. Grazing of diatoms was incorrectly included twice where the grazing of dinoflagellates was included only once. Correcting this resulted in an increase in the diatom population and a decrease in dinoflagellates.

With the model code errors corrected, the parameters calibrated in the Budd Inlet Scientific Study were re-evaluated by Ecology to determine if calibration to the 1996-1997 data was still acceptable. Because some differences were noted, Ecology re-calibrated the Budd Inlet region of the model for the 2008 draft report. The re-calibrated model at that stage was used as the tool for evaluating the model scenarios that were presented in the 2008 draft report (Roberts et al 2008).