

Memorandum

To: Files

From: Mindy Roberts

Date: July 23, 2014

Subj: Summary of independent review of Budd Inlet and Capitol Lake modeling (2008 – 2012)

Ecology requested two paid independent peer reviews of the Budd Inlet and Capitol Lake modeling.

- Cadmus Group and Portland State University (2008 – 2011)
 - Dr. Scott Wells is a professor at Portland State University (<http://web.cecs.pdx.edu/~scott/>). Dr. Wells is the Chair and Professor of the Department of Civil and Environmental Engineering. His expertise is modeling surface water hydrodynamics and water quality. He teaches graduate courses in surface water quality modeling, numerical methods, and environmental fluid mechanics.
- Cadmus Group and HDR-HydroQual (2012)
 - Jim Fitzpatrick is a national expert on hydrodynamic and water quality models. He has developed and applied numerical models to water bodies across the country and internationally.

All comments from both reviews were completed to the satisfaction of both independent reviewers.

Cadmus Group and Portland State University (2008 – 2011)

Summary: The final report and response to comments addressed all of the 2008 – 2011 independent review comments to the satisfaction of the independent reviewer.

In 2008 and 2009, we worked with the USEPA through their national consultant pool to conduct a paid independent review of the coupled Budd Inlet and Capitol Lake model. In November 2008, Jayne Carlin of EPA Region 10 executed a work order with Cadmus Group to conduct the review. Cadmus subcontracted with Dr. Scott Wells of Portland State University. The scope of work included the following elements:

1. Model Development Review

Review all model input files (e.g. boundary conditions, meteorology, bathymetry, control file, time-variable, kinetics, etc.) for appropriateness and possible errors. Plot all time-series model input files for appropriateness and possible errors.

2. Model Calibration Review

Review both sets of model calibration/confirmation results and calibration parameters used for appropriateness and possible improvements.

3. Model Scenario Analysis Review

a. Review the model input files used for scenario analysis of various alternative loading for appropriateness and possible improvement.

b. Review the post-processing results for appropriateness and possible errors in the Cumulative Frequency Distribution tool.

4. Documentation

Memorandum summarizing model review comments and recommendations.

5. Project Management

a. Scoping conference call with the Task Order Manager (TOM) and others as requested by the TOM to discuss the project and provide the key information. Summarize key agreements reached during conference call.

b. Develop a technical approach document and submit for review to TOM and others as requested by TOM.

c. Meet with TOM and others or conduct a conference call to discuss the findings of the independent technical review (can be cancelled if no meeting is deemed necessary).

Cadmus delivered the 169-page draft technical memorandum with its findings to Jayne Carlin of EPA, who then forwarded to Ecology, on February 4, 2009. This included a detailed appendix but also had 46 specific comments pertaining to the Deschutes River, Capitol Lake, or Budd Inlet modeling tools. Ecology continued to develop the modeling tools in response to the independent review comments as well as the external review comments. Ecology developed a draft response to the comments in December 2009. However, the modeling team shifted focus to the South Puget Sound model development, which was a higher priority. This was communicated to Cadmus and EPA and the Cadmus contract was extended two years.

Ecology completed the response to comments, along with the revised technical report, in December 2011. The final model runs were not substantially different from the 2008 external review draft version, although we made one code change that was subject to a subsequent independent review (See Cadmus and HDR-HydroQual review below.) Attachment 1 includes the December 15, 2011 email to Jayne Carlin (EPA), Laura Blake (Cadmus), and Scott Wells (Portland State University) delivering the response to the independent review comments.

On December 27, 2011, the modeling team held a conference call with EPA, Cadmus, and Portland State University to discuss the responses to comments.

Scott Wells (Portland State University) delivered the draft final review document to Jayne Carlin (EPA), Laura Blake (Cadmus), and me on December 28, 2011. Because the document still had a “draft” watermark, I asked Dr. Wells to resubmit the documents without it. Dr. Wells sent the final review document on December 28, 2011. See Attachment 1 for final delivery email. The final report and response to comments addressed all of the 2008 – 2011 independent review comments to the satisfaction of the independent reviewer.

Cadmus Group and HDR Engineering (2012)

Summary: The final report addressed the 2012 independent review comments to the satisfaction of the independent reviewer.

Partly in response to the Cadmus/Portland State University independent review, Ecology modified the model code. Because this had not been reviewed by Scott Wells (Portland State University) during the independent review, we requested a second paid independent review through EPA Region 10 in November 2011. The previous contract with Cadmus expired in December 2011.

Cadmus did not have staff available with the expertise requested:

“... phytoplankton kinetics (exchange of material between phytoplankton, water, and sediments). Expertise in 3-dimensional water quality modeling in estuary and freshwater systems is needed, and in particular, expertise in modeling phytoplankton in marine systems.”

I emailed Lewis Linker of EPA’s Chesapeake Bay Program, and he identified Jim Fitzpatrick of HydroQual and Dominic DiToro of the University of Delaware as having the necessary skills to evaluate these model components. I forwarded his email to EPA Region 10.

EPA contracted with Cadmus Group, which hired Jim Fitzpatrick (HDR-HydroQual), to perform the second targeted independent review with the following scope:

Task 1: Project Administration

1.1 The Contractor will set up a Kick-Off conference call with the Task Order Manager (TOM) and the Project Team (Team) which includes all of the technical contacts listed under “contacts” in this technical direction. This conference call will cover the background, scope, goals, schedule, and projected outcomes and outputs. The contractor will summarize the key points, outcomes and action items from that conference call.

1.2 The Contractor will set up conference calls with Team members whenever a draft product is available for review or if major issues are found. The Contractor will summarize the key points, outcomes and action items from each conference call.

Task 2: Technical Approach/Recommendations

2.1 The Contractor will develop a technical approach document no longer than 2 pages. This technical approach will describe how the review will be conducted, including a detailed description of what will be covered in the review. If there are comments from the Team, the Contractor will finalize the technical approach and prepare a response to comments (either as a separate document or as a tracked version of the revised approach document). Addressing the comments and developing a response to comments document (or tracked version) should take no longer than 0.5 hours.

2.2 The Contractor will review the Fortran code of the GEMSS water quality modules WQCBM and GAM to verify that the model theory and code adequately represents physical and biological processes--specifically phytoplankton kinetics (exchange of material between phytoplankton, water, and sediments). Ecology will provide access to the model code, existing documentation, access to correspond with the modeler, draft model development/calibration report, and other essential documentation as needed.. If the model review entails making additional adjustments to the coefficients and evaluating the results of such changes on a model run to test the response of the model, Ecology will perform up to a few model runs when provided by the Contractor the specifics on what to change in the test runs. Before specifying any additional model runs the contractor will thoroughly review the existing documentation of the extensive model QA verification tests in the draft report to avoid redundant testing. The Contractor will prepare a draft memorandum outlining concerns and recommendations.

2.3 If there are comments from the Team, the Contractor will finalize the draft memorandum and prepare a response to comments (either as a separate document or as a tracked version of the revised memorandum). Addressing the comments and developing a response to comments document (or tracked version) should take no longer than 0.5 hours.

On January 4, 2012, Ecology, EPA, Cadmus Group, and HDR-HydroQual held a conference call to clarify the scope and identify logistics for accessing the Fortran code. Laura Blake delivered the draft independent review on February 13, 2012. The 5-page document identified a light unit conversion in the source code but overall found that "... the model code is performing in a mass conserving and functionally expected manner." Further, the model calibration review found that "the model modifications to include vertical swimming for the dinoflagellates appears to be functioning correctly and has resulted in an improved model calibration." See Attachment 2 for the email and attached memorandum.

In response to the conversion factor comment, Greg Pelletier consulted with Jim Fitzpatrick directly, as well as Tim Wool (EPA modeler) and Bob Ambrose (retired EPA modeler). We changed the conversion factor for Watts/m² to micro-Einstein/m²-sec from 4.15 to 4.6 in the model code prior to finalizing the

model runs. The final report addressed the 2012 independent review comments to the satisfaction of the independent reviewer.

Attachment 1 – Communications with Scott Wells (Portland State University), Laura Blake (Cadmus Group), and Jayne Carlin (EPA) on the 2008-2011 Independent Review

From: Scott Wells [mailto:scott@cecs.pdx.edu]
Sent: Wednesday, December 28, 2011 2:54 PM
To: Roberts, Mindy (ECY); Carlin.Jayne@epamail.epa.gov; 'Laura Blake'; bergerc@cecs.pdx.edu
Cc: Erickson, Karol (ECY); Pelletier, Greg (ECY); Kendra, Will (ECY); Cusimano, Bob (ECY)
Subject: RE: Budd Inlet revised report

Mindy: Here it is w/o watermark, Scott

From: Roberts, Mindy (ECY) [mailto:MROB461@ECY.WA.GOV]
Sent: Wednesday, December 28, 2011 2:44 PM
To: scott@cecs.pdx.edu; Carlin.Jayne@epamail.epa.gov; 'Laura Blake'; bergerc@cecs.pdx.edu
Cc: Erickson, Karol (ECY); Pelletier, Greg (ECY); Kendra, Will (ECY); Cusimano, Bob (ECY)
Subject: RE: Budd Inlet revised report

Thanks very much – your review improved our work.

Can you finalize without the draft watermark?

Mindy

From: Scott Wells [mailto:scott@cecs.pdx.edu]
Sent: Wednesday, December 28, 2011 2:01 PM
To: Roberts, Mindy (ECY); Carlin.Jayne@epamail.epa.gov; 'Laura Blake'; bergerc@cecs.pdx.edu
Cc: Erickson, Karol (ECY); Pelletier, Greg (ECY); Kendra, Will (ECY); Cusimano, Bob (ECY)
Subject: RE: Budd Inlet revised report

All: Here is the draft of our final memo. Let me know if anyone has any comments/corrections/suggestions. Thanks again for talking yesterday about the updated model – it is clear that a ‘whole-lotta-work’ has been done. Many kudos to the modeling team, Scott

From: Roberts, Mindy (ECY) [mailto:MROB461@ECY.WA.GOV]
Sent: Thursday, December 15, 2011 3:04 PM
To: Carlin.Jayne@epamail.epa.gov; Laura Blake; bergerc@cecs.pdx.edu; Wells, Scott
Cc: Erickson, Karol (ECY); Pelletier, Greg (ECY); Kendra, Will (ECY); Cusimano, Bob (ECY)
Subject: Budd Inlet revised report

The revised draft report is available for download from our FTP site: <ftp://www.ecy.wa.gov/bicl/>. We did not merge all of the files, but here's a map of which files are which:

- Response to comments – **1_GEMSSModelReview_Response_121511.docx** has your original comments plus our responses in table form.
- Revised report – You have two choices:
 - **2a_Capitol Lake and Budd Inlet Dissolved Oxygen (gp 20111215) (clean copy).doc** has the revised version of just the Capitol Lake and Budd Inlet models section
 - **2b_DeschutesBudd_TMDL_extrev2_1211_workingversion_indrev.doc** is the full report, with the Capitol Lake and Budd Inlet models beginning on page 206. Mostly for context since all but three of the comments involved Capitol Lake and Budd Inlet, which we would like to focus on for this review.
- Appendices are in separate files
 - Appendices G through N (except Appendix J) provide additional detail on the Budd Inlet and Capitol Lake model recalibration efforts, including GEMSS code review and tests. These are in separate individual files, and some appendices have multiple parts.
 - **Deschutes_appendicesC_F_1211extrev.docx** has Appendices C through F (no significant changes from October 2008)
 - Appendix J was eliminated but we have not re-lettered the report yet
- Supplemental Information
 - **Readme.doc** – brief overview of model changes for the latest draft, review of code, model QA testing, source code, and supporting documents of model theory, modeling approach, and parameter estimation methods (including link to browse output from all model runs used for calibration).
 - **GEMSS-WQCBM.doc** – documentation of model equations for the WQCBM module
 - **kamykowski_et_al_1988.pdf** – journal article cited in GEMSS-WQCBM.doc for basis of equations for vertical migration of dinoflagellates

Let us know if you have any questions before our call on December 27. I'll be out of the office after tomorrow and checking emails infrequently, but contact Greg or Karol directly if you need something right away. On the 27th, I'll be in an airport, so let me know if the background noise is too much and I'll defer to other Ecology people for that call.

Thanks again for this review, and we really appreciate that you accommodated our schedule on finalizing this report.

Mindy

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Attachment 2 – Communications with Jayne Carlin and Laurie Mann (EPA), Laura Blake (Cadmus), and Jim Fitzpatrick (HDR-HydroQual) on the 2012 Independent Review

From: Laura Blake [mailto:Laura.Blake@cadmusgroup.com]
Sent: Friday, March 23, 2012 5:31 AM
To: Roberts, Mindy (ECY); Carlin.Jayne@epamail.epa.gov; Mann.Laurie@epamail.epa.gov; Ragsdale, Dave (ECY); Pelletier, Greg (ECY); Erickson, Karol (ECY); Kendra, Will (ECY)
Cc: Fitzpatrick, James (Jim.Fitzpatrick@hdrinc.com)
Subject: RE: Budd Inlet/Capitol Lake WQ Model Review

Hi Mindy,

I don't believe I replied to this email yet (it's still in my inbox, so I assume I didn't). Thanks for getting back to us on this. I hope the review was helpful, and provided you with what you were looking for. Good luck with the next phase(s) of this project!

Laura

From: Roberts, Mindy (ECY) [mailto:MROB461@ECY.WA.GOV]
Sent: Thursday, March 15, 2012 7:55 PM
To: Laura Blake; Carlin.Jayne@epamail.epa.gov; Mann.Laurie@epamail.epa.gov; Ragsdale, Dave (ECY); Pelletier, Greg (ECY); Erickson, Karol (ECY); Kendra, Will (ECY)
Cc: Fitzpatrick, James
Subject: RE: Budd Inlet/Capitol Lake WQ Model Review

Yes, we consider the review complete.

We did make the change suggested to the light conversion, and we don't anticipate the need for any detailed response to comments on our part.

Thank you again for working with us on this – we appreciate this independent review of our work.

Mindy

From: Laura Blake [mailto:Laura.Blake@cadmusgroup.com]
Sent: Monday, March 12, 2012 8:49 AM
To: Roberts, Mindy (ECY); Carlin.Jayne@epamail.epa.gov; Mann.Laurie@epamail.epa.gov; Ragsdale, Dave (ECY); Pelletier, Greg (ECY); Erickson, Karol (ECY); Kendra, Will (ECY)
Cc: Fitzpatrick, James
Subject: RE: Budd Inlet/Capitol Lake WQ Model Review

Hi Mindy and others

Just checking in on the status of Ecology's potential response/comment to Jim's review of the model. Trying to get a sense for when this "project" will wrap up.

Thanks,

Laura

From: Laura Blake
Sent: Monday, February 13, 2012 11:29 AM
To: Roberts, Mindy (ECY); Carlin.Jayne@epamail.epa.gov; Mann.Laurie@epamail.epa.gov; Ragsdale, Dave (ECY); Pelletier, Greg (ECY); Erickson, Karol (ECY); Kendra, Will (ECY)
Cc: Fitzpatrick, James
Subject: Budd Inlet/Capitol Lake WQ Model Review

Attached and ready for your review is the memorandum that summarizes Jim's review of the model.

Please let me know if you would like to schedule a call to discuss Jim's comments.

Laura

Laura J. Blake

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GEMSS/WQ3DCB Code Review

Dinoflagellate Equations and Literature Review

James Fitzpatrick (HDR|HydroQual), subcontractor to The Cadmus Group, Inc.

Introduction

At the request of the U.S. Environmental Protection Agency and the State of Washington's Department of Ecology, a review of the dinoflagellate kinetics used in the Budd Inlet/Capitol Lake water quality model was performed. The review included the following tasks:

1. Review of Model Theory
 - a. Review the Kamykowski et al. (1988) paper upon which the dinoflagellate phytoplankton state-variable in the Budd Inlet/Capitol Lake model is based.
2. Review of Source Code
 - a. Review the WQ3DCB module within the GEMSS model code to establish consistency between the theory presented in Kamykowski et al. paper and its implementation within the GEMSS model.
 - b. Review Appendix J.1 (GEMSS Code Review as performed by Robert Ambrose) and Appendix J.2 (GEMSS code corrections by Ecology).
3. Review of Verification Tests for GEMSS
 - a. Review the Verification Tests performed by the State of Washington's Department of Ecology on the GEMSS model as an additional confirmation of the correctness of the GEMSS phytoplankton code.
4. Review of Model Calibration Results
 - a. A limited review of the model calibration results was performed. The purpose of this review was to evaluate whether the model responded as expected to variations in various model parameters related to phytoplankton growth dynamics.

Task 1. Review of Model Theory

The Kamykowski et al. (1988) paper was reviewed. The paper presents a summary of experimental findings concerning the swimming ability of *Gyrodinium dorsum*, a photosynthetic marine dinoflagellate, in response to changes in temperature, light intensity and buoyancy. In addition, the paper presents the results of the application of a computer model to predict the instantaneous translational velocity of *G. dorsum* against observed data. The paper presents the development of a model framework that characterizes swimming speed as a non-linear function of temperature (without time lag), a hyperbolic function of light, and Stokes' law dependent equation for settling. The resulting model framework essentially establishes a temperature and phototaxic dependency for swimming. Although the reviewer is not familiar with the implementation of such a model framework in other commonly accepted

computer codes (such as WASP, EFDC, CE-QUAL-ICM, RCA, Delft3D), the theoretical basis presented in the Kamykowski paper appears reasonable and is supported by the experimental data. Further, the Kamykowski et al. paper has been cited in at least 18 other peer-reviewed journal articles, as found by a Google Scholar search. In addition, a number of papers have reported similar observations of diel vertical migration for dinoflagellates that support the model framework developed by Kamykowski et al. (ex., Kamykowski and Yamazaki, 1997, MacIntyre et al., 1997, Ralston et al., 2007, Hall and Paerl, 2011).

A difference between the phototaxic-based swimming model for dinoflagellates developed by Kamykowski et al., (1988) and more recent models of dinoflagellate swimming is the addition of metabolism influences, i.e., nutrient-based affects (Kamykowski and Yamazaki, 1997, Liu et al., 2001). However, as reported by Aura Nova Consultants and J.E. Edinger Associates (1999), field data in the Budd Inlet seldom indicated nutrient depletion, therefore, including metabolism influences on swimming behavior of dinoflagellates is likely not necessary.

Review of Source Code

The GEMSS WQ3DCB module was reviewed to establish consistency between the theory presented in the Kamykowski et al. (1988) paper and its implementation within the GEMSS model. This reviewer found that the theory presented in the Kamykowski et al. paper was properly implemented in the GEMSS code, but did identify the following issues:

1. In converting radiation from Watts/m² to μEinstein/m²-sec, a conversion factor of 4.15 (lines 369 and 425) was used. Assuming that PAR represents the 400-700 nm spectral range of solar radiation used for photosynthesis and assuming that 550 nm as the average of that range and which is typically used for the conversion, a value of 4.6 should be used for the conversion factor. However, as will be shown below, the value of 4.15, which was used in the model, is unlikely to have a significant affect on the model computations.

The value of 4.6 results from the following computations:

$$1 \frac{\text{Einstein}}{\text{m}^2\text{-day}} \times \frac{6.02 \times 10^{23} \text{ quanta}}{\text{Einstein}} \times \frac{\text{Watts-sec}}{2.77 \times 10^{18} \text{ quanta}} \times \frac{\text{day}}{86400 \text{ sec}} = 2.515 \frac{\text{Watts}}{\text{m}^2}$$

$$\text{or } 1 \text{ Watt/m}^2 = 0.3976 \text{ Einstein/m}^2\text{-day} \times 10^6 \mu\text{Einstein/Einstein} \times \text{day}/86400 \text{ sec} = 4.6 \mu\text{Einstein/m}^2\text{-sec}$$

(ref: http://www.seabird.com/pdf_documents/ApplicationNotes/appnote11GeneralFeb11.pdf)

2. The Kamykowski et al. (1988) paper provided a functional description of the light dependency of the swimming speed for *G. dorsum* as

$$S_L = S_M [\tanh(\alpha I / S_M)],$$

where S_L is the swimming speed at light intensity I , S_M is the asymptotic maximum swimming speed and α is the initial slope.

For *G. dorsum*, Kamykowski et al. reported a value of $S_M = 109.89 \mu\text{m}/\text{sec}$ and $\alpha = 0.55 \mu\text{m}^2/\mu\text{Einstein}$. The values reported and used in the Washington Department of Ecology model were $S_M = 35 \mu\text{m}/\text{sec}$ and $\alpha = 10 \mu\text{m}^2/\mu\text{Einstein}$. Figure 1 presents a comparison between the Kamykowski et al. coefficient set and the Washington Ecology coefficient set. As can be seen, the Kamykowski coefficient set (Figure 1a) provides more of a hyperbolic shape than does the Washington Department of Ecology coefficient set (Figure 1b) for the range of PAR presented in the Kamykowski et al. paper. It is not until you get to low values of PAR that the hyperbolic shape becomes evident (Figure 1c). This is not a problem with the implantation of the Kamykowski et al. theory, but rather, apparently reflects a choice in model coefficients necessary to achieve satisfactory calibration to observed field data. The end result is that the coefficient set reflects more of an “on/off” or binary switch for swimming speed as a function of ambient light, i.e., if there is any light then the dinoflagellates will begin swimming and will swim at an almost constant speed of $35 \mu\text{m}/\text{sec}$.

As mentioned in (1) above, the conversion factor of 4.15 as opposed to a value of 4.6 has almost no effect on the resulting model computations for swimming speed (see Figure 2). The difference between swimming speeds using the 4.15 vs. 4.6 conversion factor is less than a few percent and only at very low light intensities.

Review of Verification Tests for GEMSS

A review of the verification tests for the GEMSS code was performed and all tests results verify that the model code is performing in a mass conserving and functionally expected manner.

Review of Model Calibration Results

A limited review of the model calibration results, including the by Aura Nova Consultants and J.E. Edinger Associates (1999) report, indicates that the model modifications to include vertical swimming for the dinoflagellates appears to be functioning correctly and has resulted in an improved model calibration.