Memorandum

To: Andrew Kolosseus (Water Quality Program)

From: Mindy Roberts (Environmental Assessment Program)

Cc: Anise Ahmed, Greg Pelletier, Skip Albertson, and Karol Erickson (Environmental Assessment Program)

Date: May 8, 2014

Subject: Response to independent review comments received on the report *South Puget Sound Dissolved Oxygen Study: South and Central Puget Sound Water Circulation Model Development and Calibration*

In January 2010, we received comments from John Hamrick of TetraTech on the 2009 external review draft report *South Puget Sound Dissolved Oxygen Study: South and Central Puget Sound Water Circulation Model Development and Calibration*. TetraTech was contracted by EPA Region 10 to perform a paid independent peer review of the circulation report. TetraTech's scope of work included the following items:

1. Review appropriateness of selected models
2. Summarize observational data to support model configuration, calibration and validation, and scenario simulation
3. Review model configuration
4. Review model calibration
5. Review model validation and sensitivity and uncertainty analysis
6. Review model scenario selection and results
7. Review model report and associated documentation

In 2010, the modeling team proceeded with the development of the water quality model after addressing the independent review. However, Ecology did not finalize the circulation report until this month.

The table below compiles comments from the independent peer review as well as responses to the comment. Responses include both edits reflected in the final document and direct responses to the comment.

Comment	*Comment heading*	Comment details	Response
1	***Review Appropriateness of Selected Models***	The selection of the GEMSS model is well described in the cited reference [3] and the model's capabilities meet the defined needs of the study. It is noted that a number of other available modeling systems were omitted from the score-based evaluation in [3], however ECY's previous experience with GEMSS and it capabilities would tend to make its selection none controversial even in the absences of numerical rating. The description of the GEMSS model provided is adequate, but the few references that are cited are difficult to obtain. A more definitive list of references including detailed technical documentation, such as [1], and referred journal articles would be desirable.	Thanks. We have included three additional journal articles on GEMSS software.
2	***Summarize Observational Data to Support Model Configuration, Calibration and Validation, and Scenario Simulation***	Observational data sources used for model configuration, calibration and validation, and scenario simulation are well presented in the report. A number of additional documents, including [1,2,4] were obtained and reviewed.	Thanks
3	***Review Model Configuration***	Model configuration is defined as the sequence of steps leading to an operational model and includes selection of spatial resolution and grid development, selection of temporal simulation periods and assembly of corresponding forcing functions, boundary and initial conditions, and preliminary selection of adjustable model parameters. This task evaluates the forcing functions, boundary, and initial conditions from a general perspective as to suitability and use of appropriate processes. Detailed quality review of model input data is addressed separately in optional task 8. Subtasks include:	NA
3.1	*<u>Model Spatial Resolution and Grid Development</u>*	A somewhat more detailed discussion of the origin of the horizontal model grid and its unique mapping features would be appropriate as well as how this grid was accommodated into the GEMSS model. The separate Appendix A, [5] provides a very detailed description of interpolation of bathymetry onto the model grid and the vertical layering. Some discussion of the selection of a Cartesian or 'Z' vertical grid as opposed to terrain following or sigma vertical grids used in a number of previous model applications to Puget Sound would be in order.	A detailed discussion of the origin of the model grid is presented in Albertson et al. 2002b which is cited in the report. The model grid was later incorporated into GEMSS and extended to Edmonds by Environmental Resource Management to accommodate nutrient sources in Central Sound that could potentially influence dissolved oxygen in South Sound. Language to this effect has been added to the report. A comparison of models and model selection discussion is included in Albertson et al. 2007b

3.2	<u>*Selection of Model Temporal Simulation Period*</u>	The calibration and validation period are based on 2006-2007 field observation periods. Partitioning of the period into separate calibration and validation periods follows well accepted procedures. Since a number of previous model studies of Puget Sound have been conducted and calibrated to older observational data sets, a brief discussion of why these data were not used or the superiority of the used data set would be useful.	Previous completed studies (e.g. Budd Inlet and Oakland Bay) were for a period different than 2006-2007. Data from those years were not used since the water quality data gathered for 2006-2007 were more robust and complete for the South and Central Puget Sound domain.
3.3	<u>*Circulation Model Boundary Conditions and Forcing Functions*</u>		
	3.3.1 Hydrodynamic open boundary conditions for water surface elevation and/or inward-outward wave propagation	There is a short discussion of the problem of specification of the water surface elevation open boundary at Edmond using the results of a previous one-dimensional tidal model [2] since the only long-term observation stations in Elliott Bay and Commencement Bay are far away. Since the model is harmonically forced, a harmonic boundary condition at Edmonds can be readily generated by calibration to the Elliott Bay and Commencement Bay harmonics. As noted the water surface open boundary condition is based on harmonic generated water surface elevation. There is not discussion of sub-tidal frequency water surface elevation forcing. Analysis of the NOAA record at Elliott Bay indicates a sub-tidal variation in water surface elevation, however this variation is relatively small compared the principal harmonic amplitudes. A discuss of sub-tidal forcing and how it is incorporated or why it is neglected should be included.	Subtidal forcing of the open boundary was not incorporated in the model. As the reviewer noted, this component is expected to be relative minor. Subtidal residual flows at various locations within the model domain were found to be in reasonably close agreement with published values from other sources.
	3.3.2 Open boundary conditions for salinity and temperature	Monthly time scale salinity and temperature observations near the west and east side for the open boundary were used for boundary conditions. Liner interpolation was used to produce model time step scale temporal values. This approach is generally acceptable. The approach was illustrated using depth-time contour plots of salinity and temperature which are somewhat difficult to visually evaluate. Time series plots for salinity and temperature at a number of depths would be complimentary. A question to consider if longer term water quality simulations are to be conducted is how to extend the boundary conditions to different time period. Fourier analysis has been shown to work well for temperature, while regression relationships between global fresh water inflow and spring-neap tidal phase are promising for salinity.	Extrapolating the boundary conditions beyond the simulation period is not within the scope of the present project. We appreciate the ideas for extending boundary conditions should we undertake this in the future.
	3.3.3 Point and distributed fresh water inflows and associated temperatures	The development of fresh water inflows to the systems is thorough and well documented in the model report and referenced data reports.	Thanks

	3.3.4 Surface wind stress forcing functions and its spatial representation	See next section.	NA
	3.3.5 Atmospheric forcing including surface wind stress and thermal forcing functions and water column-sediment bed thermal coupling	Observational data for wind and atmospheric thermal forcing are associated with four observational stations. How the various locations are used in described in a context of refining the model calibration. A summary table listing parameters such as wind speed and direction, air temperature, relative humidity, solar short wave radiation and cloud cover and which stations were used to provide data would clarify the final configuration. Also when data from multiple locations is used, the method of interpolation onto the model grid should be described.	A description of spatial distribution of meteorological data has been added to the final report.
3.4	*Circulation Model Initial Conditions*	The method of defining initial conditions for salinity and temperature is well described. The rationale for using three zonal averages rather than interpolation of actual profiles merits some discussion. There are a number of procedures for level surface profile interpolation. Repetitive simulation of a short spin up period such as the first month would also be an option.	The rationale of using three zones was based on average temperatures that were distinctly different between deeper region north of Tacoma Narrows, somewhat deeper region just south of Tacoma Narrows and the shallow region (encompassing the finger inlets) in South Puget Sound. It should be noted that in each of these three regions there were three vertical regions as well. So, there were 9 spatial regions in total. GEMSS does not a have a built in spatial interpolator for initial conditions. The spin up time in GEMSS is short, on the order of 10 to 15 days (Entrix, JE Edinger Associates and Gahagan and Bryant Associates. 2001. "Hydrodynamic and water quality modeling and feasibility analysis of Indian River, Rehoboth Bay and Little Assawoman Bay"http://www.southbethany.org/cwq/HassanFlushingStudy2001-1.pdf) South Sound has a flushing (e-folding) time of 3 months and the period of interest for water quality are the months of September and October which are several e-folding times past initial conditions.
3.5	*Circulation Model Options and Parameters*		

	3.5.1 Numerical solution options and time step size, which influence model accuracy and stability.	A short paragraph summarizing alternate numerical solution schemes used should be included, particularly the advection scheme which influences the time step and stability. The time step, or range of times steps, if dynamic time stepping is used should be stated.	We added a section to the report to address. The three transport schemes (Upwind, QUICKEST, and QUICKEST with ULTIMATE) within GEMSS were evaluated but the best result (with respect to model stability) was obtained using higher order transport scheme, "QUICKEST with ULTIMATE". Upwind scheme assumes that the concentration at the face of a grid cells equal to the concentration of the grid upstream of the face. QUICKEST (Quadratic Upstream Interpolation for Convective Kinematics with Estimated Streaming Terms) employs a three point upstream biased interpolation scheme to calculate face concentrations. QUICKEST with ULTIMATE (Universal Limiter for Transient Interpolation Modeling for Advective Transport Equation) applies a limiter to each cell face to prevent any overshoot or undershoot. Other details of the transport scheme are present in GEMSS user's manual available from Environmental Resource Management (ERM). A dynamic time-stepping scheme was used with an initial time step of 10 seconds and a maximum allowable timestep of 120 seconds during the simulation period, except in the last week of January 2007 where a maximum time step of 10 seconds was allowed due to model instability. These time steps were derived following sensitivity runs to obtain the best combination of stability and computational time.

	3.5.2 Bottom boundary resistance and wind stress parameter specification	A short description of bottom roughness and its sensitivity is presented based on dimensionless Chezy coefficients which are not widely used in three-dimensional hydrodynamic models. The relationship between the Chezy coefficient and absolute roughness measures such as the log law roughness height, z_o, or equivalent sand grain roughness, k_s, should be provide with appropriate reference as to how the Chezy coefficient is used in GEMSS.	In GEMSS, Chezy Coefficient for bottom roughness can be entered in two ways: 1. As a constant Cz0 2. As a 'power law' depth variable coefficient Cz = Cz0 (d/d0)^n with a selector box that can limit minimum Chezy to Cz0 In South Puget Sound application of GEMSS we used a constant Chezy coefficient (Cz0) to define bottom roughness. However, we varied this constant regionally with a coefficient of 20 for shallower inlets and 40 for deeper areas. Given the general agreement with tidal current velocities (both u and v) and tidal elevations, temperature and salinity, we believe that the selected Chezy coefficients are appropriate. However, for formulation of Chezy coefficient within GEMSS we would refer you to GEMSS user manual available from ERM. Venkat Kolluru (ERM, personal communication April 2014) indicates that Chezy formulation in GEMSS is similar to that in CE-QUAL-W2.
	3.5.3 Adjustable turbulence closure and mixing parameters	The GEMSS model has options for a number of turbulence closure schemes and the particular scheme used should be stated.	We added a paragraph to the report to summarize the option selected. GEMSS solves the turbulent time average Reynolds momentum equations in three dimensions. GEMSS includes three models to parameterize turbulence. These are: 0-Equation, 1-Equation and 2-Equation. The first and the third method did not always work. 0-Equation worked with any of the available options for mixing lengths. 1-Equation worked with only a few of the available options for mixing lengths. 2-Equation was associated with most failures (model crashed) and the successes were with very low computational timesteps. In the end 1-Equation was selected with Von Karman's mixing length based on model stability and optimum computational time steps. Details of these methods are present in GEMSS user's manual available from Environmental Resource Management (ERM).
	3.5.4 Adjustable atmospheric thermal forcing	The section on atmospheric thermal forcing provide some discussion of refinement of the thermal forcing to achieve temperature calibration	Thermal forcing was not adjusted to achieve temperature calibration. Specification of thermal forcing was limited to use of observed data without adjustment.

	and heat exchange parameters		
4	***Review Model Calibration***		
4.1	*Water Surface Elevation Calibration*	An extensive set of time series plots are presented which qualitatively confirm that the model's ability to predict tidal frequency water surface elevation is very good. Quantitative RMS errors are also shown in the time series plots and are within acceptable ranges. Presenting these RMS errors in tabular form is suggested. It would also be useful to normalize the RMS using the RMS of the PStide predict which is used in lieu of actual observations, Since the model is forced by harmonic constituent generated open boundary water surface elevations, harmonic comparison in Table 4 provides an additional quantitative measure of calibration. Agreements between predicted amplitudes and phases and corresponding observation based amplitudes and phases from Elliott Bay and Commencement Bay are good with the larger M2 and K1 amplitudes being within 5 percent. Phase errors are somewhat easier to interpret when stated in minutes rather than degrees, however making the conversion indicates that phase error are less than 15 minutes for all constituents and less than 5 minutes for the M2. There is some concern about sub-tidal forcing and response as noted in comment 3.3.1.	RMSE for model predicted surface elevation and those predicted by PStides were included in each plot rather than a table to provide a connection between visual comparison with the magnitude of the comparison. Actual observations were compared with both PStides as well as model predictions for two NOAA stations and RMSE were included for these comparisons. Concerns with subtidal forcing have been addressed previously (see response to comment 3.3.1 above). The overall phase shifts included in the text of the report now includes the equivalent minutes for ease of interpretation. The phase shifts in the tables are left in degrees due to space restrictions.

4.2	*Velocity Calibration*	Velocity calibration utilized both surface mounted ADCP transects and bottom mounted continuous deployments. Considering the variety of sources of error and uncertainty in making transect comparisons, many of the section average velocities agree well with observations, particularly when areas are in close agreement. Alternative comparisons for transect data might consider interpolation of sub-sections of transects into horizontal model grid cells and comparing transports at the grid cell level. Results form bottom mounted, continuous deployed ADCP measurements were compared with model predictions in visual time series format with corresponding error measures. Comparisons were made for near surface east and north velocity components with corresponding RMS error measures. The vertical scaling of the time series plots should be increased to facilitate better visual comparison. Since the comparison periods are on the order of 14 days, an alternate comparison would involve estimation of principle current direction for observations and model predictions and showing a single time series plot of the velocity vector component along the principal direction and corresponding principal direction based RMS errors. These RMS errors could also be normalized by the RMS of the observations. Summary presentation of principal directions and errors in a tabular form would also be useful.	Ecology agrees that there may be benefit in comparing transport at the grid level rather than for the whole transect. However, the grid level transport may be better substantiated by the bottom mounted ADCP rather than interpolating the transact data for a single day. This comparison has been included in the report for several stations. Because the u (east-west) and v (north-south) component of ambient currents have different magnitudes, the plotting scale for each station was based upon the maximum of these two components. Since the magnitudes of these components also varied with station location, the plotting scale for each station also varied accordingly. Additional graphs have been included that plot all the observed water column data including mean, maximum and minimum velocities. The RMSE were based upon average water column velocities as suggested. Ecology believes that including RMSE on the plots provides a better visual connection between data and the error statistic.

4.3	*Temperature and Salinity Calibration*	Temperature and salinity calibration included visual comparison of surface patterns for six days encompassing the calibration and validation periods, visual and quantitative time series comparison at different levels in the water column, and visual and quantitative comparison of profiles. The graphical comparison of observed and predicted surface temperature and salinity shows good agreement, however the different formats used for observations and model predictions make the comparison somewhat tedious. Displaying observations on the model grid rather than a map would provide a better visual grounding for the viewer. Another alternative is to show the colored observational circles on the model grid based predictions, with the size of the graphics expanded to a full page. Using this approach, differences between observation values and the immediate surrounding predicted values tend to stand out. This comparison could also be made quantitatively using spatial summed mean absolute errors or RMS errors. Visual and quantitative time series comparisons of salinity and temperature follow standard procedure and the results appear reasonable. Tabular summary of RMS errors by station and position in the water column would make overall comparison easier. Although RMS errors generally provide the most stringent measure, other measures including mean absolute errors might be considered. Also normalization of the errors by the RMS or average of the observations would be useful.	Thanks. The report now contains time-depth plots for observed and predicted temperature and salinity that shows the whole water column temperature or salinity as a function of time for a particular grid cell. These also include the associated overall RMSE. Plan view maps showing spatial distribution of predicted and observed temperature and salinity have also been included for surface layer. A section on overall statistical errors has been added However, a separate table with just the RMSE for all stations is not included. Ecology believes that the RMSE attached with individual plots is a better way to present the error statistics.
4.4	*Additional Comments*	The comparison of Brunt-Vaisala frequency is interesting and generally shows that the model reproduces the general profiles.	Thanks
5	**Review Model Validation and Sensitivity and Uncertainty Analysis**		
5.1	<u>Model validation</u>		
	5.1.1 Water Surface Elevation Validation	Time series plots and RMS errors are presented for a validation time period different than the calibration period. Similar levels of performance seem to be obtained. A table showing RMS errors for the calibration and validation periods would be helpful for quick comparison as opposed to going back and forth between plots. This would be the same table suggested in comment 4.1.1.	The report no longer has a distinct calibration and validation period. The report now uses the whole simulation period as calibration period since the distinction between the calibration and validation period is an artificial one as the model is run for the whole simulation period each time during the calibration process.
	5.1.2 Velocity Validation	Comparisons of observed and predicted velocities were not separated in calibration and validation periods.	see response to comment to 5.1.1
	5.1.3 Temperature and Salinity Validation	Temperature and salinity time series and profile comparisons are presented for the validation period in the same format as was used for calibration. Generally the level of agreement appears consistent; however tabular comparison of errors by station and/or water column level would provide a useful summary.	see response to comment to 5.1.1

	5.1.4 General Comment on Calibration and Validation	Summaries of errors for both calibration and validation in tabular form are recommended, as well as additional normalized errors. Regression measures might also be considered. Comparison of error ranges for this study with other larger estuary studies would also be useful.	see response to comment to 5.1.1. Circulation patterns have been compared to literature values and the comparison included as a table.
5.2	Sensitivity and Uncertainty Analysis	The report contains a short paragraph discussing sensitivity to open boundary conditions which is sufficient. Two other sensitivity considerations are also addressed in relation to calibration. The first was respect to bottom friction and is addressed in comment 3.5.2. The second considered sensitivity to vertical layering and presented a strong argument to support using 17 rather than 35 vertical layers at the expense of a slight change in water surface elevation prediction. The sensitivity also considered vertical layer thickness near the water surface. It is somewhat troubling that the model is unstable with a surface layer thickness of 3 meters. The report also indicates that using a stable 4 meter thick layer increased run time, however the report and Appendix A document the use of a 4 meter surface layer. The fact that vertical profiles are well predicted may make these comments moot.	The stability involves the tide range in South Puget Sound. Since vertical profiles are well predicted, we did not further explore layering schemes with the model.
6	**Review Model Scenario Selection and Results**	No specific model scenarios, which are more relevant to water quality simulations, were conducted. Flushing or residence time simulation experiments and dye release experiments were conducted. Experiments of this type are useful to gain some insight into system behavior. The difference in time scales obtained using different definitions of flushing time vary significantly and the most appropriate value is difficult to determine in the absence of field observations.	NA
7	**Review Model Report and Associated Documentation**		
7.1	Assigning chapter, section and sub-section numbering to the report sections would more easily allow referencing both internally and externally. This task will be concluded if the model report is revised subject to provided comments.		Thanks. The report has been reorganized and revised. Ecology's current publication standard is *not* to number chapters and sections.
7.2	*Supporting Documentation*	Support documentation including QAPP, data reports, and model documentation were provided and are judged to be acceptable for external review purposes.	Thanks
7.3	*Links to Modeling Software and Input Files*	Access to the model code, executables, and input files has been provided. A readme file describing the contents of the directories would be useful for further review and essential for archival purposes. Additional comments are anticipated with further review of this material	Thanks

8	***References***
	[1] ERM, 2006. GEMSS-HDM, Hydrodynamic and Transport Module, Technical Documentation. April 2006, 42 pp.
	[2] National Oceanic and Atmospheric Administration, 2002. Tidal Datum Distributions in Puget Sound Washington Based on a Tidal Model. Technical Memorandum OAR PMEL-122, November 2002, 39 pp.
	[3] Washington Department of Ecology, 2007. South Puget Sound Water Quality Study, Phase 2: Dissolved Oxygen, Quality Assurance Plan. Publication No. 07-03-101, August 2007, 70 pp.
	[4] Washington Department of Ecology, 2008a. South Puget Sound Dissolved Oxygen Study, Interim Data Report. Publication No. 08-03-037, August 2007, 70 pp.
	[5] Washington Department of Ecology, 2008b. South Puget Sound Dissolved Oxygen Study – South and Central Puget Sound Water Circulation Model Development and Calibration: Appendix A, Model Grid Development Dated December 18, 2008, 4 pp.
	[6] Washington Department of Ecology, 2009. South Puget Sound Dissolved Oxygen Study – South and Central Puget Sound Water Circulation Model Development and Calibration. External Draft Review Version Dated October 15, 2009, 155p.