DEPARTMENT OF ECOLOGY
State of Washington

Addendum 1 to Quality Assurance Project Plan

Puget Sound Dissolved Oxygen Modeling Study: Intermediate-scale Model Development

October 2011

Publication No. 09-03-110-Addendum-1

Publication Information

Addendum

This addendum is an addition to an original Quality Assurance Project Plan. The addendum is not a correction (errata) to the original plan.

This addendum is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/0903110Addendum1.html

Ecology's Activity Tracker Code for this study is 09-503.

Original Publication

Quality Assurance Project Plan: Puget Sound Dissolved Oxygen Modeling Study – Intermediate-scale Model Development.

Publication No. 09-03-110.

The Quality Assurance Project Plan is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/0903110.html

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October 7, 2011

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SUBJECT: Addendum 1 to Quality Assurance Project Plan for Puget Sound Dissolved Oxygen Modeling Study: Intermediate-scale Model Development
Activity Tracker Code: 09-503
Publication No: 09-03-110

The Washington State Department of Ecology (Ecology) has been awarded a grant under EPA's Puget Sound Scientific Studies and Technical Investigations Assistance Program for ongoing support of Ecology's Puget Sound Dissolved Oxygen Modeling Study. Funds are to be used to develop Puget Sound 2.0, the next generation analytical tool focused on circulation and dissolved oxygen dynamics. Puget Sound 2.0 will be used to evaluate impacts of changing human and climate influences.

This addendum to the Quality Assurance Project Plan for Puget Sound Dissolved Oxygen Modeling Study: Intermediate-scale Model Development provides details of specific activities to be completed under Puget Sound 2.0.

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Abstract

Puget Sound basins experience low oxygen levels that do not meet state water quality standards established under the federal Clean Water Act (CWA) to protect aquatic life. A primary concern regarding impairment of Puget Sound is to what extent human and natural sources contribute to low levels of dissolved oxygen in the bays and inlets of the Sound. The Washington State Department of Ecology (Ecology) is developing Puget Sound 2.0, the next generation analytical tool focused on circulation and dissolved oxygen dynamics. Puget Sound 2.0 will be used to evaluate impacts of changing human and climate influences. The Environmental Protection Agency (EPA), Pacific Northwest National Laboratory (PNNL), University of Washington Climate Impacts Group (UW-CIG), and Ecology have jointly initiated this water quality model development project to address the following nutrient management questions.

- Are human sources of nutrients in and around Puget Sound significantly impacting water quality?
- How much do we need to reduce human sources of nutrients to protect water quality in Puget Sound?

The model simulates full eutrophication kinetics and has been calibrated using data collected in Puget Sound during 2006. The calibrated model, using best available information, will simulate the effects of future nutrient-loading, population growth, and climate change for calendar years 2020, 2040, and 2070.

The specific objectives of Puget Sound 2.0 are to:

- Refine the calibration of the water quality model to conditions observed in 2006.
- Evaluate sensitivity of the model to various input parameters and boundary conditions.
- Apply the model to a series of future climate and human scenarios to identify and quantify potential impacts.

Findings from this study will be communicated through detailed project reports and web-based materials for both scientists and the general public.

Background

Municipal and industrial wastewater generated in various cities and the counties around Puget Sound enters the fjordal waters of Puget Sound via numerous outfalls currently permitted through the National Pollutant Discharge Elimination system. Nonpoint runoff from watersheds direct to marine waters, stormwater outfalls from urban areas, and combined sewer overflows (CSOs) are also major sources of pollution to the surface waters of Puget Sound.

In addition to the conventional point and nonpoint direct sources, 19 major rivers enter the Puget Sound basin and contribute pollutant loads to Puget Sound from their corresponding watersheds. The long-term tidal circulation and water renewal from the Pacific Ocean help flush out resident water. In recent years, however, there has been considerable concern over the assimilative capacity of Puget Sound and ability to withstand continued human population growth.

Historic studies of the oceanographic properties of Puget Sound show that advective mixing over the sills near the Admiralty Inlet entrance and near the southern end of the main basin at the Tacoma Narrows creates a two-layered circulation system with net outflow through the mixed surface layer. This is discussed in the work of Ebbesmeyer and Barnes (1980). This balance of surface outflow of buoyant freshwater and the corresponding inward-bound compensation current is essential to sustaining the water quality and overall health of Puget Sound.

Fjords tend to become anoxic, especially in the presence of a sill. This is also the case in parts of Puget Sound, such as Lynch Cove and Dabob Bay in the Hood Canal, where low dissolved oxygen (DO) conditions have been observed since the 1950s (Barnes and Collias, 1958; Collias et al., 1974). This study is also of great interest due to recurring fish kills in the early 2000s (Curl and Paulson, 1991; Paulson et al., 2007; Newton et al,. 2007). Other parts of Puget Sound such as South Puget Sound have also experienced low DO levels (Roberts et al., 2009). As a result, there is considerable interest in understanding the effects of hydrodynamics, basin flushing characteristics, and the effect of nutrient loads entering Puget Sound on DO and overall water quality.

The Clean Water Act mandates managing pollutant loading to meet water quality standards. To meet this requirement, the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) have initiated a Puget Sound Dissolved Oxygen model-development project. Ecology contracted with Pacific Northwest National Laboratory (PNNL) to develop an intermediate-scale hydrodynamic and water quality model. The model will be used to (1) study dissolved oxygen (DO) and nutrient dynamics, (2) evaluate the effects of current and potential future nutrient loads on DO levels in Puget Sound, and (3) define potential Puget Sound-wide nutrient management strategies and decisions. The overall objective of the Puget Sound Water Quality model is to address the following nutrient management questions:

- Are human sources of nutrients in and around Puget Sound significantly impacting water quality?
- How much do we need to reduce human sources of nutrients to protect water quality in Puget Sound?

Upon completion, this model is expected to help design and plan potential Puget Sound-wide management strategies and support site-specific detailed work that may be needed. The development of the hydrodynamic and water quality model of Puget Sound has two major components: (1) a 3-D coastal hydrodynamic model and (2) a water quality model that simulates DO and algal dynamics. The hydrodynamic component of the “Puget Sound Nutrient and DO Model” is complete (Yang et al., 2009). The water quality model component has been completed in draft form and has been submitted for review (Khangaonkar et al., 2011).

As shown by similar efforts in other parts of the U.S. (e.g., Chesapeake Bay, Florida Bay, San Francisco Bay), comprehensive model development of this nature is most effective when executed through a long-term commitment. Model development occurs over multiple years and through many short steps, each providing continuing improvement. Phase 1 helped establish the hydrodynamic and water quality numerical modeling domain for the entire Puget Sound and Georgia Basin region of interest (Salish Seas). This was a major first step forward. We can now examine the entire Puget Sound/Salish Sea.

As anticipated, the model's preliminary results interested the community who requested the use of the model to examine various water quality impacts around Puget Sound. Phase 1 results and requests for information from interested users also revealed aspects of the model which could use additional refinement and improvement in model performance.

This study will address these key questions:

- To what extent do human and natural sources contribute to low levels of DO in the bays and inlets in Puget Sound?
- Are these Puget Sound-wide questions, or can they be addressed at a more focused scale?
- Could climate change affect Puget Sound's biogeochemical balance and impact DO?
- What can we do to avoid human-caused low oxygen levels, both now and in the future?

The Department of Ecology implements the federal Clean Water Act in the state of Washington, considering the physical, chemical, and biological health of the water bodies. Ecology must address impaired water bodies, including Puget Sound. However, interpreted in its broadest sense, this function also supports a wide variety of management actions at all levels in the Puget Sound region.

The overall goal of this proposed project is to conduct Phase 2 of the development of the Water Quality (nutrients, algae and DO) model of Puget Sound. Phase 2 work will develop Puget Sound 2.0, the next generation of analytical tools focused on both circulation and dissolved oxygen dynamics. It will improve data management and communication of results. Phase 2 work will focus on refining the model, improving the performance, and applying the model to a selected set of questions including the effects of climate change on Puget Sound Water Quality. These steps will help develop the model to a state of robustness and readiness of a "Water Quality Management Tool" for use by EPA and Ecology and the Puget Sound Restoration community in general.

Circulation Model

External reviews and comments received during Phase 1 of the project prompted Ecology to consider implementing refinements to the existing circulation model. External reviewers included the Project Advisory Committee, composed of representatives from federal, state, and local governments; tribes; universities; businesses; and environmental organizations. A paid independent review was also completed. Ecology will contract PNNL to refine the existing circulation model.

Refinements

The model was designed and implemented at an intermediate scale such that 1-year-long simulations could be conducted efficiently. In the initial setup, effort was made to limit the number of model grid elements while still providing adequate resolution of the shoreline. While this may have worked in other coastal plain estuaries, in the fjordal waterbody of Puget Sound it led to an undesirable response associated with the sigma-stretched coordinate system. The consequence of lower grid resolution was that excessive mixing resulted due to pressure gradient errors from sigma coordinates in the areas with steeply sloping bathymetry. Targeted improvements to the circulation model will include the following:

- Evaluate the number of vertical layers and the layering scheme, considering concentrating layers near the surface.
- Adjust bathymetry to represent nearshore features and minimize numerical errors associated with the effects of hydrostatic pressure on rapidly varying depths.
- Quantify impacts of bathymetric adjustments on total volume and for individual sub-basins within Puget Sound (South Sound, Main Basin, Whidbey Basin, and Hood Canal).
- Provide residence time estimates (using a passive tracer) for individual sub-basins within Puget Sound (South Sound, Main Basin, Whidbey Basin, and Hood Canal). Evaluate residual estuarine flow at key locations in the model domain; Strait of Juan de Fuca, Admiralty Inlet, and Tacoma Narrows.
- Evaluate influence of ocean salinity and temperature boundary conditions.
- Include all watershed contributions to the flow balance, including wastewater treatment plants discharging to marine waters and smaller stream contributions in addition to the 19 gauged river inflows to the U.S. portions of the model domain. Also include at a coarse scale all freshwater inflows from the Canadian portion of the model domain.
- Evaluate the performance and applicability of the North American Regional Reanalysis (NARR) data products, using statistical comparisons with observed meteorological data at key locations in the model domain. Update model to accommodate spatially-varying meteorological input files and develop scripts to convert available data to spatially varying meteorological input for future use.
- Revisit initial conditions to improve model performance, particularly in Hood Canal.

Calibration

Numerous sensitivity tests were performed as part of Phase 1 which helped with model calibration and initial selection of model coefficients. Upon completion of the tasks outlined above, model performance will be re-assessed and new coefficients will be determined. For the Phase 2 effort it will be necessary to:

- Evaluate model performance as measured by root mean square error or other appropriate statistics. Performance measures include:
    - Temperature, salinity, density, and Brunt-Vaisala frequency profiles at representative stations throughout the model domain. Temperature, salinity, and density time series in the surface and bottom layers at representative stations throughout the model domain
- Conduct sensitivity tests by perturbing key model parameters, including:
    - Meteorological boundary conditions (wind, solar radiation, net heat flux).
    - Freshwater boundary conditions (river flow and temperature).

Water Quality Model

Refinements

The Phase 1 water quality report was not yet reviewed externally; however, the internal review developed specific recommendations for Phase 2. These include:

- Refine algal productivity kinetics to better represent salient features of primary production in Puget Sound (e.g., improved timing of spring phytoplankton bloom, separate spring and fall phytoplankton blooms).
- Ensure that simulated time series of key water quality parameters, especially DIN and DO, reflect the expected seasonal patterns and end-of-year recovery.
- Determine how/if other CE-QUAL-ICM users accommodate temporally-varying and spatially-regionalized model parameters. Determine if CE-QUAL-ICM can be updated appropriately (within the time and budget available for this project). If so, PNNL will incorporate spatially and temporally variable benthic fluxes of nitrogen and dissolved oxygen to improve model performance.
- Include all watershed contributions, such as wastewater treatment plants discharging to marine waters, smaller stream contributions, and the 19 gauged river inflows to the U.S. portions of the model domain. Also include, at a coarse scale, nutrient contributions from all freshwater inflows (river and wastewater treatment plants discharging to marine waters) from the Canadian portion of the model domain.
- Revisit initial conditions to improve model performance, particularly in Hood Canal.

Calibration

Numerous sensitivity tests were performed as part of Phase 1. This helped with model calibration and initial selection of model coefficients. Upon completion of the tasks outlined above, model performance will be re-assessed and new coefficients will be determined. For Phase 2 it will be necessary to:

- Evaluate model performance as measured by root mean square error or other appropriate statistics. Performance measures include:
  - Nutrient, dissolved oxygen, and chlorophyll profiles.
  - Nutrient, dissolved oxygen, and chlorophyll time series in the surface and bottom layers at representative stations throughout the model domain.
- Conduct sensitivity tests by perturbing key model parameters, including:
  - Ocean boundary conditions (nutrient and dissolved oxygen profiles).
  - Freshwater boundary conditions (river and wastewater treatment plant nutrient levels).
  - Phytoplankton kinetics (maximum growth rate, optimum temperature, optimum light, nitrogen and phosphorus half-saturation rates, carbon-to-chlorophyll ratios, sinking rates).
  - Zooplankton kinetics (grazing rate).
  - Benthic processes (nitrogen and dissolved oxygen flux).

Scenarios

Current Conditions

The Phase 2 circulation and water quality model will be used to simulate a series of current and future scenarios to quantify relative contributions from humans and climate influences (Table 1).

PNNL will evaluate the relative contributions of human and natural phenomenon to low dissolved oxygen under current loads using the differences in oxygen levels under four scenarios:

1. Natural conditions with no point sources and rivers set to natural nutrient levels.
2. No point sources but rivers set to current levels that reflect both natural and upstream human contributions (nonpoint sources).
3. Current contributions from point sources (wastewater treatment plants discharging to marine areas) and nonpoint sources (rivers with natural and upstream human contributions).
4. Current contributions from point sources plus rivers set to natural nutrient levels

Table 1. Proposed current and future model scenarios to be simulated.

Scenario	Scenario Type	Meteorology, Hydrographic & Ocean conditions from:	Point Source Loading (WWTPs)	Nonpoint Source Loading (rivers)
1	Natural Condition	2006	None	Natural nutrient levels
2	Current loading & climate	2006	None	Current nutrient levels
3	Current loading & climate	2006	Current nutrient levels	Current nutrient levels
4	Current loading & climate	2006	Current nutrient levels	Natural nutrient levels
5	Current loading with Climate Change	2020	Current nutrient levels	Current nutrient levels
6	Current loading with Climate Change	2040	Current nutrient levels	Current nutrient levels
7	Current loading with Climate Change	2070	Current nutrient levels	Current nutrient levels
8	Future loading with Climate Change	2020	2020 nutrient levels	2020 nutrient levels
9	Future loading with Climate Change	2040	2040 nutrient levels	2040 nutrient levels
10	Future loading with Climate Change	2070	2070 nutrient levels	2070 nutrient levels

These scenarios will be evaluated by comparing model output for the 2006 simulation period. Graphics and basic statistical summaries will express spatial and temporal patterns in dissolved oxygen, nutrients, and chlorophyll. Daily minimum dissolved oxygen concentrations will be calculated for each model grid cell (water column minimum) for each of the four scenarios. PNNL will report daily minimum concentrations differences between scenarios 1 and 2; 1 and 3; and 1 and 4 and provide results of these scenarios to Ecology before completing future scenarios.

Future Conditions

Dr. Alan Hamlet, of UW-CIG, will provide expertise in the area of climate change research and work collaboratively with PNNL and Ecology to develop scenarios corresponding to future climatological, meteorological, and hydrological conditions. Input files will be available for calendar years spanning present day to 2070. From this dataset three representative years will be chosen for detailed analysis. For the purpose of this QAPP Addendum the three specific years are nominally identified as 2020, 2040, and 2070; exact calendar years chosen for simulation may differ. Ecology will develop and provide to PNNL future wastewater treatment plant and river flows and nutrient loads data.

UW-CIG, under contract to Ecology, will provide to PNNL the following input files:

- Meteorological inputs for years 2020, 2040, and 2070.
- River inflow hydrographs for years 2020, 2040, and 2070.

Ecology will provide to PNNL the following input files:

- River nutrient levels for years 2020, 2040, and 2070. Loads will reflect both natural and human contributions.
- Wastewater treatment levels for years 2020, 2040, and 2070.

To develop the future ocean boundary conditions, UW-CIG will convene a workshop that will include experts from oceanography, climate sciences, and related fields to hypothesize future ocean conditions to specify as boundary conditions to the model domain. The focus of the workshop will be on the best approach for estimating future ocean conditions. PNNL will develop the 2020, 2040, and 2070 ocean boundary conditions based on the experts workshop in consultation with UW-CIG and Ecology. PNNL will prepare explanatory text, suitable for inclusion in an Ecology report, of how the ocean boundary conditions were estimated.
Using the boundary conditions described above, 6 model scenarios will be developed to evaluate the effects of future climate change and human pollutant loads, hereafter referred to as Scenarios 5-10 (Table 1).

Current Pollutant Loading with Climate Change

Scenarios 5, 6, and 7 will be run using current pollutant loading (as in scenario 3 above) and 2020, 2040, and 2070 meteorology, hydrographic, and ocean boundary conditions (Table 1). PNNL will provide graphics and basic statistical summaries that express spatial and temporal patterns in salinity, temperature, dissolved oxygen, nutrients, and chlorophyll for each of the scenarios. PNNL will provide daily minimum water column dissolved oxygen concentrations by model grid cell for each of the scenarios. These scenarios will be evaluated by comparing model output for the future climate scenarios to current natural conditions (scenario 1 above). PNNL will provide differences between daily minimum water column concentrations between scenarios 5 and 1; 6 and 1; and 7 and 1 for each model grid cell.

Future Pollutant Loading with Climate Change

Scenarios 8, 9, and 10 will be run using future pollutant loading estimates developed by Ecology and 2020, 2040, and 2070 meteorology, hydrographic, and ocean boundary conditions (Table 1). PNNL will provide graphics and basic statistical summaries that express spatial and temporal patterns in salinity, temperature, dissolved oxygen, nutrients, and chlorophyll for each of the scenarios. PNNL will provide daily minimum water column dissolved oxygen concentrations by model grid cell for each of the scenarios. PNNL will provide differences between daily minimum water column concentrations between scenarios 8 and 5; 9 and 6; and 10 and 7.

Approach for Developing Climate Change Model Inputs

Meteorological Inputs

UW-CIG will prepare projected future meteorological data sets based on existing runs from the Weather Research and Forecasting (WRF) regional climate model (Salathé et al. 2010). The future climate change scenario will be based on a transient ECHAM5 A1B scenario and products will be developed for calendar years 2020, 2040, and 2070 (Salathé et al. 2010). Daily time step gridded data sets at 1/16th degree resolution will be prepared for the following variables:

- Precipitation
- 2 m air temperature
- Incoming solar radiation
- Incoming longwave radiation
- Relative humidity
- Wind speed
- Wind direction

These data will be used to create inputs and associated future scenarios for the PNNL hydrodynamic model.

Hydrodynamic Inputs

UW-CIG has coupled the Variable Infiltration Capacity (VIC) model to the 1/16th degree meteorological driving data sets and downscaled climate change scenarios discussed above for several watersheds and rivers entering Puget Sound [http://www.hydro.washington.edu/2860/]. UW-CIG will extend these existing data sets to generate simulated daily hydrographs of estimated regulated river flow for fifteen major rivers (Table 2) entering Puget Sound for future conditions corresponding to the ECHAM5 A1B scenario described above. Observed effects of storage and diversions on river flow will be accounted for using quantile mapping techniques, statistically relating natural flows simulated by the hydrology models to observed regulated flows.

Table 2. River Locations for Hydrologic Products.

	River Site Name	USGS Number
1	Dosewallips River at Brinnon	12053500
2	Duckabush River near Brinnon	12054000
3	Hamma Hamma River near Hoodsport	12055000
4	Black River at Little Rock	12029000
5	Deschutes River at E St Bridge at Tumwater	12080010
6	Puyallup River at Puyallup	12101500
7	Green River near Auburn	12113000
8	Skokomish River near Potlatch	12061500
9	Nisqually at Alder Dam	12085000
10	White River at Buckley	12100000
11	Skykomish River near Gold Bar Wa	12134500
12	Snohomish River near Monroe	12150800
13	NF Stillaguamish River near Arlington	12167000
14	Skagit River near Mount Vernon	12200500
15	Nooksack River at Ferndale	12213100

Flows from ungaged rivers and watersheds will be estimated by choosing a representative reference river based on its similarity to an ungaged area and then multiplying the reference flow by the ratio of the ungaged to gaged areas (Lincoln, 1977). Ecology will also work closely with PNNL and UW-CIG to develop a strategy for estimating future Canadian river flows. The methods used to estimate ungaged and Canadian hydrodynamic inputs will be reviewed by the Project Advisory Committee and summarized in the final methods report.

Point and Non-Point Sources

Ecology will work closely with PNNL and UW-CIG to develop strategies for estimating future U.S. and Canadian concentrations and loads for point and non-point sources for key water quality parameters. The strategy for point sources wastewater treatment plants will likely be based on current per-capita flows and loads (Mohamedali et al., 2011), adjusted to account for anticipated population growth in 2020, 2040, and 2070. Ecology is also considering developing point source scenarios that simulate anticipated improvements in wastewater treatment technology.

The strategy for non-point sources will build on the 1999-2008 analyses completed in Phase 1 of the project (Mohamedali et al., 2011). To extrapolate these results to 2020, 2040, and 2070 it will likely be necessary to investigate historical and projected trends in water quality as a function of land-use and population changes. Ecology anticipates developing a more sophisticated strategy for estimating nitrogen concentrations and loads, but will consider simpler alternatives for other water quality parameters that the model is less sensitive to. The methods to be developed to estimate point and non-point concentrations and loads will be reviewed by the Project Advisory Committee and summarized in the final methods report.

Ocean Boundary Conditions

UW-CIG (Dr. Alan Hamlet) will help to lead and organize a 1-day workshop on Climate Change Effects and Impacts on Puget Sound Water Quality sponsored by Ecology. The workshop will include experts from oceanography, climate sciences, and related fields to hypothesize future ocean conditions to specify as boundary conditions to the model domain. PNNL will develop the 2020, 2040, and 2070 ocean boundary conditions based on the experts workshop in consultation with UW-CIG and Ecology. PNNL will prepare explanatory text, suitable for inclusion in an Ecology report, of how the ocean boundary conditions were estimated.

Organization and Communication

Ecology will conduct monthly conference calls and meetings as needed to discuss model calibration progress and next steps. Working with Ecology, PNNL will develop a standardized set of post-processed model output (primarily graphical output and basic statistical summaries) that will be created for each new model run in order to facilitate ongoing communications related to calibration strategy and status. Notes and meeting minutes from the monthly conference calls will be incorporated into quarterly and semi-annual reports for which Ecology is responsible.

Project Deliverables and Schedules

Ecology will conduct model development and complete deliverables in accordance with updated schedule shown in Table 3.

PNNL will provide Ecology with a draft and final model calibration report. The final Ecology documentation for this project will be in the form of separate methods and project reports. Both PNNL and UW-CIG will participate in final report development. Their activities will include:

- Providing report subsections to Ecology that summarize the findings of the present and future climate scenarios
- Reviewing the draft report.
- Collaborating with Ecology on web-based information exchanges to enhance communication of outputs.

Table 3. Project Deliverables and Schedules.

Circulation model improvements	Due date	Lead staff
Modifications completed	12/31/2011	PNNL
Water quality model improvements	Due date	Lead staff
Modifications completed	3/31/2012	PNNL
Draft model calibration report		
Author lead / support staff	PNNL	
Schedule		
Draft due to Ecology	5/31/2012	
Final model calibration report and response to external and independent review comments		
Author lead / support staff	PNNL	
Schedule		
Final due to Ecology	9/7/2012	
Final (all reviews done) due to publications coordinator	9/30/2012	
Final report due on web	10/31/2012	
Model simulations of current and future conditions		
Author lead / support staff	PNNL	
Schedule		
Model output of current conditions	5/31/2012	
Complete setup and model input files for 2020, 2040, and 2070 scenarios; provide explanatory text detailing methodology	5/31/2012	
Model output of future conditions	8/31/2012	
Future model forcing data		
Author lead / support staff	UW	
Future meteorological forcing data based on WRF simulations	12/31/2011	
Future flow scenarios for approximately 15 river locations in Puget Sound based on ECHAM5 A1B climate change	12/31/2011	
Climate change workshop		
Author lead / support staff	UW	
Workshop organization and setup	3/31/2012	

Future pollutant loading scenarios*	
Author lead / support staff	Ecology – Teizeen Mohamedali
Load scenarios based on anticipated population growth, census data, and wastewater discharge records; format as model input files. Develop text for inclusion in final methods report.	10/15/2011
Final methods report*	
Author lead / support staff	Ecology – Brandon Sackmann
Schedule	
Draft due to project team	5/31/2012
Draft due to advisory committee	7/20/2012
Final (all reviews done) due to publications coordinator	9/30/2012
Final report due on web	10/31/2012
Final project report – Part 1, Current Scenarios*	
Author lead / support staff	Ecology – Brandon Sackmann
Schedule	
Draft due to project team	7/31/2012
Draft due to Ecology management	8/15/2012
Draft due to advisory committee	9/30/2012
Final project report – Part 1 + 2, Current + Future Scenarios*	
Author lead / support staff	Ecology – Brandon Sackmann
Schedule	
Draft due to project team and Ecology management	1/31/2013
Draft due to advisory committee	3/31/2013
Final (all reviews done) due to publications coordinator	5/31/2013
Final report due on web	6/30/2013
Semi-annual progress reports to EPA	
Author lead	Ecology – Brandon Sackmann
Schedule	
1st semi-annual report	10/31/2011
2nd semi-annual report	4/30/2012
3rd semi-annual report	10/31/2012
4th semi-annual report	4/30/2013
Quarterly reports for Ecology management	
Author lead	Ecology – Brandon Sackmann
Schedule	
1st quarterly report	9/30/2011
2nd quarterly report	12/31/2011
3rd quarterly report	3/31/2012
4th quarterly report	6/30/2012
5th quarterly report	9/30/2012
6th quarterly report	12/31/2012

7th quarterly report	3/31/2013

Outreach preparation – Interim/Final Model Results	
Author lead	PNNL
Outreach materials	6/30/2013
Outreach preparation – Climate Scenarios	
Author lead	UW
Outreach materials	6/30/2013
Outreach preparation – Project Description, Interim/Final Results	
Author lead	Ecology – Brandon Sackmann
Outreach materials	6/30/2013

* To be entered into Ecology’s Activity tracking system.

References

Barnes, C.A. and E.E. Collias, 1958. Some Considerations of Oxygen Utilization Rates in Puget Sound. Journal of Marine Research, vol. 17, No. 1, pp. 68-80.

Collias, E.E., N. McGary, and C.A. Barnes, 1974. Atlas of Physical and Chemical Properties of Puget Sound and Approaches, Washington Sea Grant 74-1, Seattle, WA.

Curl, H.C., Jr. and A.J. Paulson, 1991. The biochemistry of oxygen and nutrients in Hood Canal, In: Puget Sound Research '91 Proceedings, Volume 1, T.W. Ransom (Ed.), Puget Sound Water Quality Authority, Olympia, WA, pp. 109-115.

Ebbesmeyer, C.C. and C. A. Barnes, 1980. Control of a fjord basin's dynamics by tidal mixing in embracing sill zones, Estuarine and Coastal Mar. Science 11: 311-330.

Khangaonkar, T., T. Kim, Z.Yang, and R. Labiosa, 2011. Puget Sound Dissolved Oxygen Modeling Study: Development of an Offline Water Quality Model – Preliminary Calibration Report (Draft).

Lincoln, J.H., 1977. Derivation of Freshwater Inflow into Puget Sound. University of Washington Department of Oceanography Special Report No. 72. University of Washington, Seattle, WA. 20 pp.

Mohamedali, T., M. Roberts, B. Sackmann, A. Whiley, and A. Kolosseus, 2011. Puget Sound Dissolved Oxygen Study/Model: Interim Nutrient Load Summary for 1999-2008. Washington State Department of Ecology, Olympia, WA. Publication No. 11-XX-XXX (in prep).

Newton, J., C. Bassin, A. Devol, M. Kawase, W. Ruef, M. Warner, D. Hannafious, and R. Rose, 2007. Hypoxia in Hood Canal: An overview of status and contributing factors. In: Proceedings of 2007 George Basin Puget Sound Research Conference. Vancouver, British Columbia, March 26-29, 2007.

Paulson, A.J., D.P. Konrad, L.M. Frans, M. Noble, C. Kendall, E.G. Joshberger, R.L. Juffman, and T.D. Olsen, 2006. Freshwater and saline loads of dissolved inorganic nutrients to Hood Canal and Lynch Cove, western Washington, U.S. Geological Survey Scientific Investigations Report, 2006-5106, 92 pp.

Roberts, M., S. Albertson, A. Ahmed, and G. Pelletier. 2009. South Puget Sound Dissolved Oxygen Study – South and Central Puget Sound Water Circulation Model, Development and Calibration. External Review Draft. Washington State Department of Ecology.

Salathé, E.P., L.R. Leung, Y. Qian, and Y. Zhang, 2010. Regional climate model projections for the State of Washington. *Climatic Change* 102(1-2): 51-75, doi: 10.1007/s10584-010-9849-y.

Yang, Z., T.Khangaonkar, R.Labiosa, T.Kim, 2009. Puget Sound Dissolved Oxygen Modeling Study: Development of an Intermediate-Scale Hydrodynamic Model. Technical Report prepared for Washington State Department of Ecology. PNNL 18484.