Modeling Quality Assurance Project Plan for the Quartermaster Harbor Nitrogen Management Study

A Targeted Watershed Grant under the 2008 Puget Sound Initiative

April 2010

King County

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ABSTRACT

We propose to model freshwater inflow and nutrient loads to Quartermaster Harbor (QMH), a sensitive marine embayment of Vashon-Maury Island (VMI) in Puget Sound. We also propose to model the impact of nutrient loads, particularly nitrogen loads, on Quartermaster Harbor dissolved oxygen concentrations using a marine hydrodynamic and water quality model. The expected outcomes of the development of these models is a management tool capable of evaluating the role of nitrogen in the risk of potentially lethal, low-level dissolved oxygen events in QMH, a sensitive marine embayment of Vashon-Maury Island (VMI) in Puget Sound.

1.0. INTRODUCTION

King County was awarded a West Coast Estuaries Initiative (WEI) grant by Region 10 of the U.S. Environmental Protection Agency (EPA) to conduct the Quartermaster Harbor Nitrogen Management Study. The goal of this study is to support the protection and restoration of Quartermaster Harbor (QMH)–a high value, coastal aquatic resource on Vashon-Maury Island (VMI) in Puget Sound. Partners working with King County on this grant-funded study include the University of Washington-Tacoma (UWT), and the Washington Department of Ecology (Ecology). The WEI grant will also support the enhancement of aquatic resource protection programs in an area threatened by population growth. This Quality Assurance Project Plan (QAPP) describes the proposed development of predictive numerical models planned as part of the Quartermaster Harbor Nitrogen Management Study (King County 2009).

1.1 Problem Definition and Background

Dissolved oxygen levels below the Washington State marine water quality standard have been observed in QMH over the last four years of monthly monitoring by King County (Figure 1). Dissolved oxygen is essential for fish and other marine life - when levels fall below critical thresholds marine life can become stressed or killed or forced to escape to more oxygenated waters if possible. Low dissolved oxygen levels, combined with the high habitat value of Quartermaster Harbor and increased frequency of detection of nitrate nitrogen in VMI groundwater, in combination with ongoing population growth, make this project a high priority for King County. Quartermaster Harbor has many similarities with South Puget Sound embayments which do not meet state dissolved oxygen standards established for the protection of aquatic life.

Quartermaster Harbor was one of 19 areas of Puget Sound judged to be relatively sensitive to anthropogenic nutrient inputs (Rensel Associates and PTI 1991). The process of anthropogenic enrichment of receiving waters to nutrients and the response to enrichment is generally known as eutrophication. Excess nutrients, nitrogen compounds in particular, can lead to excessive phytoplankton and algae growth, which can then deplete oxygen concentrations when the algae die (Figure 2). Nitrogen and phosphorus are naturally occurring essential nutrients for marine plants and phytoplankton. Since phosphorus is typically abundant in marine waters, the nitrogen compounds, particularly nitrate, become the limiting factor for phytoplankton growth. This is generally found to be true in Puget Sound (Rensel Associates and PTI 1991). Eelgrass losses, fish kills, and harmful algal blooms have been attributed to eutrophication and low oxygen events in Hood Canal. There is also evidence to suggest that QMH is a source of *Alexandrium*, a single-celled organism responsible for toxic algal blooms (Greengrove *et al*. 2006). The similarity of this study area with rural lands draining to Puget Sound may allow for transferring results and knowledge gained to other locations around Puget Sound.

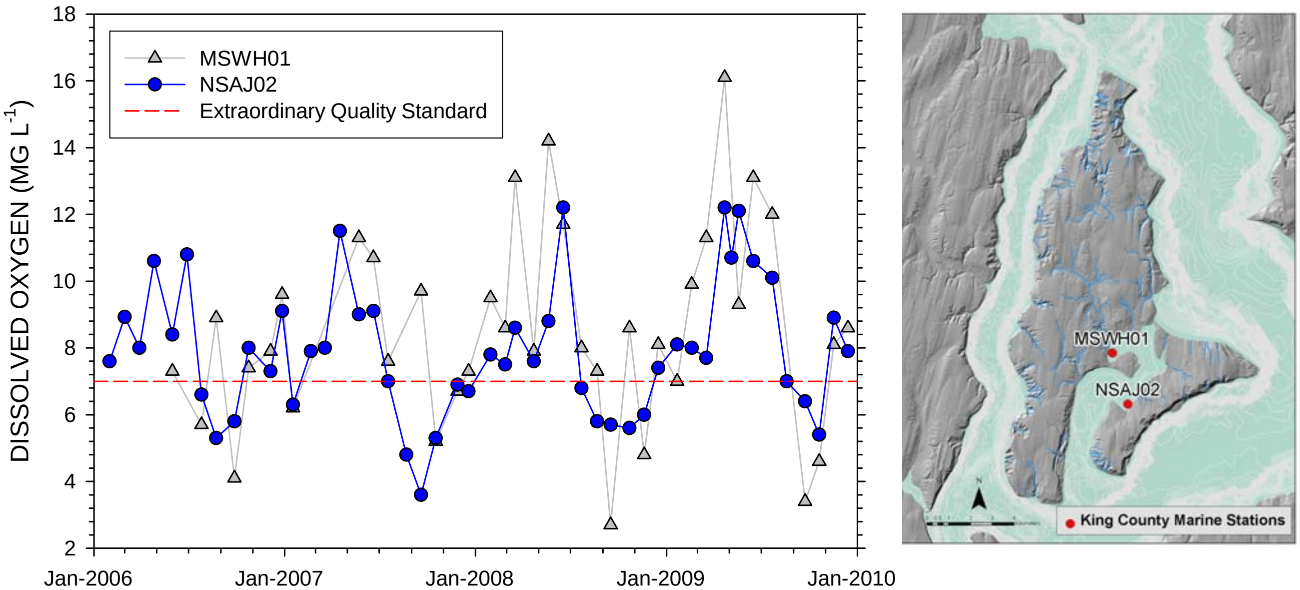

Figure 1. Monthly dissolved oxygen concentrations measured in bottom waters of Quartermaster Harbor by King County. Station MSWH01 is located in the inner harbor near Burton and NSAJ02 is located in the outer harbor near Dockton.

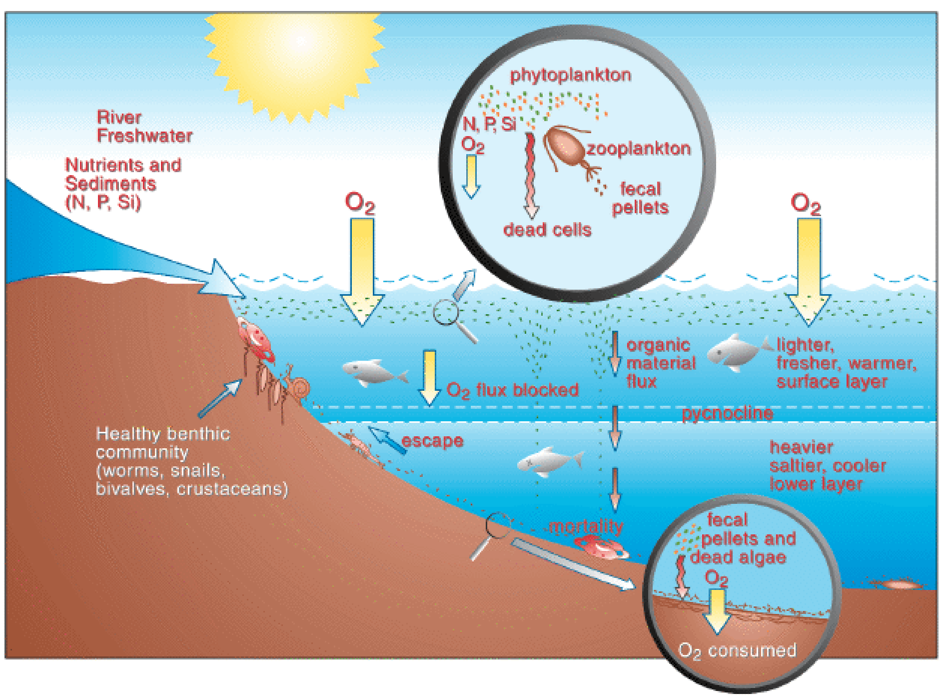

Figure 2. Conceptual diagram of marine nutrient-oxygen dynamics (Source: Downing JA, et al. Gulf of Mexico hypoxia: land and sea interactions.

Source: Task force report no. 134. Ames, IA:Council for Agricultural Science and Technology, 1999;5. http://www.ehponline.org/docs/2000/108-3/focusfig2B.GIF)

1.2 Description of Study Area

Quartermaster Harbor, located between Vashon and Maury Islands, is sheltered from the wind and waves and receives runoff from about 40 percent of Vashon-Maury Island (Figure 3). It is a shallow, protected embayment that comprises approximately 12.1 km^2 (3,000 acres) of water surface area in an inner and outer harbor. Inner QMH is especially sheltered and Judd Creek, located in the northwestern portion of the inner harbor, is the largest freshwater input. Transition zones between freshwater surface flows and the marine water within the bay include the estuaries at the mouth of Judd Creek, Fisher Creek, and Raab's Lagoon along with numerous smaller streams. Inner QMH is shallow, with a greatest depth of about 5 meters and very little tidal flushing. Outer QMH water depths range from about 11-46 meters with rapid tidal flushing.

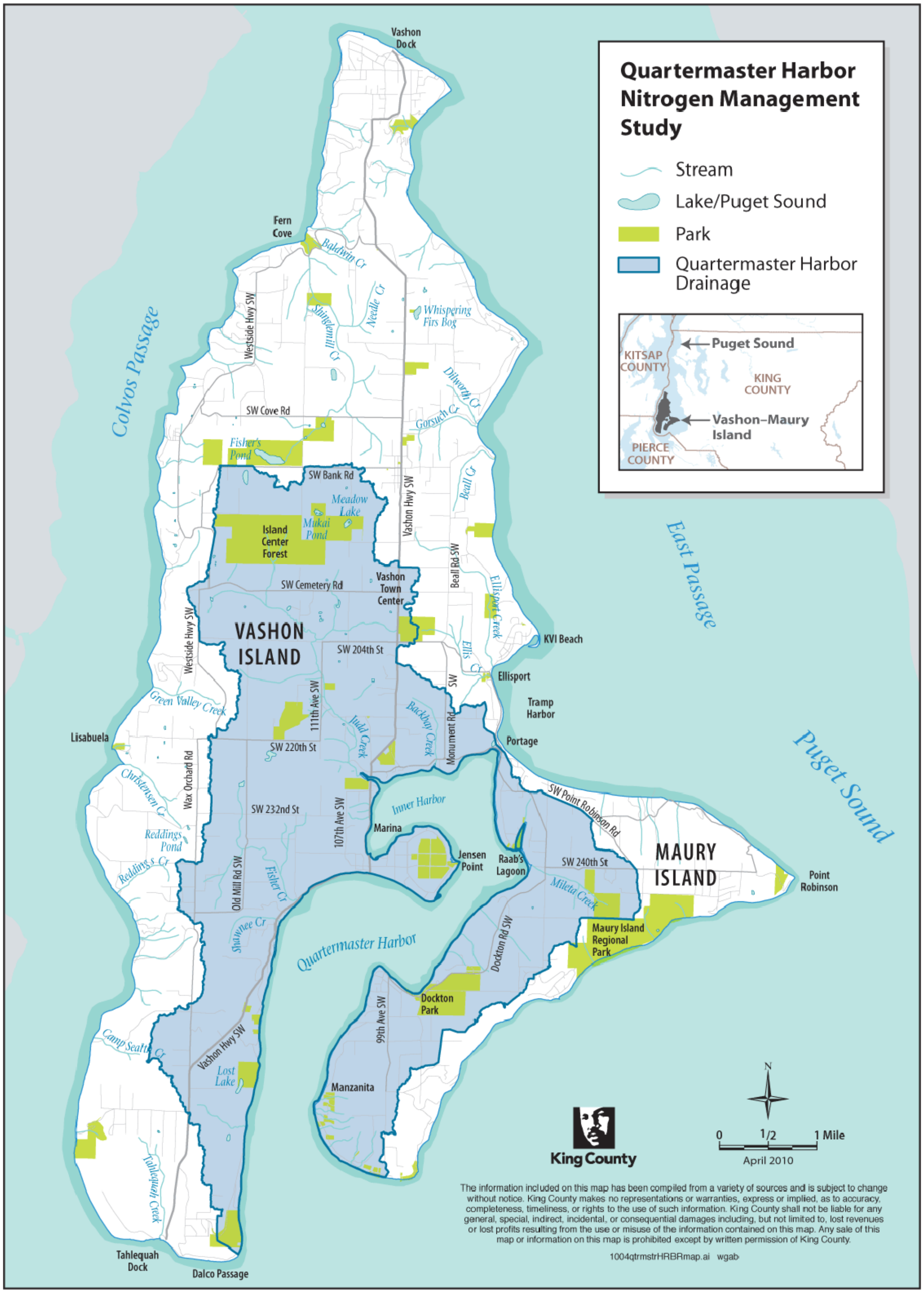

Figure 3. Map of Vashon-Maury Island highlighting the drainage area to Quartermaster Harbor.

2.0. MODELING GOALS AND OBJECTIVES

The overall goal of the Quartermaster Harbor Nitrogen Management Study is to determine how nitrogen from a variety of sources affects dissolved oxygen levels in Quartermaster Harbor. The expected long-term outcomes are improved policies in the King County Comprehensive Plan, the implementation of land use management BMPs to reduce nitrogen loading to Quartermaster Harbor, and the prevention of lethal low-level oxygen events in Quartermaster Harbor. These outcomes will be useful as a model for other rural areas of Puget Sound.

In general, the modeling goals include the development of a predictive model of terrestrial nutrient loadings (by source) coupled to a receiving water (marine hydrodynamic and water quality) model. The modeling system developed will then be used to evaluate the effectiveness of nitrogen management scenarios on Quartermaster Harbor dissolved oxygen levels, and to compare the level of effectiveness of different management options with conceptual cost estimates.

2.1 Modeling Objectives

The specific objectives of the proposed modeling effort for the Quartermaster Harbor Nitrogen Management Study are as follows:

- Develop a 3-dimensional marine hydrodynamic model of Quartermaster Harbor calibrated and tested against conditions observed in the harbor in 2009 and 2010 capable of representing the stratification induced by freshwater inflows and water exchange between the inner and outer harbor and between the outer harbor and the main basin of Puget Sound.

- Develop a 3-dimensional marine water quality model of Quartermaster Harbor (coupled or integrated with the marine hydrodynamic model) calibrated and tested against conditions observed in the harbor in 2009 and 2010 and capable of evaluating the effect of changes in nitrogen inputs on harbor phytoplankton and dissolved oxygen levels during the critical months of September and October.

- Develop a terrestrial nutrient loading model calibrated and tested using conditions observed in tributaries monitored in 2009 and 2010 that is capable of representing the effect of various management scenarios on nitrogen loading to the harbor.

- Estimate effects of various nitrogen management scenarios on Quartermaster Harbor dissolved oxygen levels.

3.0. MODELING APPROACH AND SELECTION

Modeling is an essential component of the Quartermaster Harbor Nitrogen Management Study. Modeling is proposed to evaluate to what extent dissolved oxygen conditions in Quartermaster Harbor are due to human-related inputs and changes relative to conditions prior to significant forest clearing and settlement within the drainage to the harbor. The general approach to modeling and model selection is described below.

3.1 Modeling Approach

In theory, modeling should be an iterative approach that involves initial conceptualization and implementation based on management information needs and available resources followed by testing and model refinement. However, the application of models as an aid in management decision making typically requires a more finite project timeline. Ideally, modeling and management decision making would be a coupled iterative process that allows for additional data collection, model testing, model refinement, and re-evaluation of model results and management decisions based on them.

A relatively finite timeline will be achieved through the following steps:

- Develop new models or select existing models for project application
- Review of model data needs
- Compilation and review of existing data required for model
- Identification of data gaps or additional data needs
- Additional data collection and incorporation of additional data into model
- Selection of periods for model calibration
- Model setup
- Model calibration and testing
- Identification and implementation of possible model refinements
- Final testing and calibration of individual models
- Integration of receiving water model with watershed model

Steps involved in application of individual models or integrated models to water quality management decision making are not addressed in this Quality Assurance Project Plan.

3.2 Model Selection

The most important criteria for selecting the modeling framework for this project include:

1. The framework uses algorithms and solution techniques that are appropriate for the intended application.
2. Biogeochemical modules are integrated with the hydrodynamic and transport modules and include important kinetic processes that are known to be necessary for simulation of nitrogen fate and transport and dissolved oxygen dynamics in enclosed embayments of Puget Sound.
3. Peer review of model theory and past applications has occurred.
4. Technical documentation is available.
5. Active development of the framework is ongoing and technical support is available.

In addition to these key criteria, other considerations that would be beneficial include the following:

- Successful past applications in the Puget Sound region have occurred.
- Program source code is available for review as part of program documentation.
- Graphical user interface (GUI) utilities that facilitate model setup, execution, and input and output management and analysis.
- Team members responsible for modeling tasks are familiar with the selected model(s)

A variety of models and modeling frameworks have been applied in the Puget Sound region. Perhaps the most notable recent effort to develop an integrated watershed-receiving water modeling framework is the coupling of the Distributed Hydrology-Soil-Vegetation Model (DHSVM) with the Rutgers Ocean Modeling System (ROMS) to evaluate the impact of watershed nitrogen loadings on Hood Canal dissolved oxygen levels. Additional examples reviewed by Albertson *et al.* (2007) include marine receiving water model applications such as the Environmental Fluid Dynamics Code (EFDC) application to South Puget Sound, the Generalized Longitudinal Lateral and Vertical Hydrodynamic and Transport (GLLVHT) model application to Budd Inlet, and the application of the Princeton Ocean Model (POM) to Puget Sound. Another modeling framework that has been used in Puget Sound was developed as part of a cooperative project to develop and demonstrate strategies for protecting and improving the quality of Sinclair and Dyes Inlets.[1] This Sinclair/Dyes Inlet framework uses a version of CH3D-WES maintained by the Space and Naval Warfare Systems Center (SPAWAR) coupled to watershed hydrologic models (HSPF). Estimates of contaminant loading (primarily fecal coliform bacteria) were developed through statistical modeling of land cover and stream water quality data.

Albertson *et al* (2007) compared two of the models identified above (EFDC and ROMS) to a third model (Generalized Environmental Modeling System for Surface Waters or GEMSS),

[1] ENVironmental inVESTment (ENVVEST) project http://environ.spawar.navy.mil/Projects/ENVVEST/index.html and Sinclair/Dyes Inlets Water Quality Improvement Project http://www.ecy.wa.gov/programs/wq/tmdl/sinclair-dyes_inlets/

which is the latest version of GLLVHT), and concluded that GEMSS was the preferred model for application to Phase 2 of the South Puget Sound Water Quality Study. This choice was primarily due to the inclusion of the diel vertical migration of dinoflagellates, which is considered to play an important role in dissolved oxygen dynamics in South Puget Sound.

We propose a model selection process that will identify the best system of models based on project specific criteria that include considerations of the time and resources available for this project and the current understanding of management needs.

3.2.1 Marine Hydrodynamic and Water Quality Model

Albertson et al (2007) and Sackman (2009a) developed detailed comparisons of available marine hydrodynamic and water quality models available for application to South Puget Sound and Puget Sound, respectively. Although the model(s) ultimately chosen for each project are different, similar considerations were made in selecting the final models. These considerations included previous successful applications of the models in Puget Sound, familiarity of the modeling team with the models, and incorporation of important physical and biological processes in the modeling framework (e.g., wetting/drying, sediment diagenesis).

For the South Puget Sound Dissolved Oxygen Study, Albertson et al. (2007) selected GEMSS (an integrated 3-dimensional hydrodynamic and water quality model) based on comparisons with two other models (EFDC and ROMS). GEMSS was selected due to the successful application of an earlier version of the model to a portion of South Puget Sound (Budd Inlet), the inclusion of model code to simulate the diel migration of dinoflagellates, the availability of initial parameter settings from the Budd Inlet model as a starting point for model calibration, and the availability of pre- and post-processing graphical user interface. Separate hydrodynamic and water quality models were selected by Sackman (2009a) to simulate the hydrodynamics and water quality of Puget Sound. FVCOM, an unstructured 3-dimensional model was chosen to simulate Puget Sound Circulation, which would be coupled through a hydrodynamic output file as input to the unstructured 3-dimensional CE-QUAL-ICM model. Separate models were chosen to provide the ability to run multiple water quality scenarios without the need to simulate Puget Sound circulation (if unchanged).

Given the more limited resources of the Quartermaster Harbor Nitrogen Management Study, one of the primary considerations is the familiarity of the project modeling team with the models under consideration. This criterion limits the options to GEMSS, EFDC, or a coupling of EFDC with CE-QUAL-ICM. Considering:

- the documented occurrence of dinoflagellate diel migration in Quartermaster Harbor (Nishitani *et al*., 1988) – a phenomenon that is included in GEMSS water quality modeling algorithms
- the similarity of Quartermaster Harbor to South Puget Sound embayments with similar dissolved oxygen problems that are currently being modeled using GEMSS

- the availability of an initial water quality parameter set from the recently calibrated Budd Inlet GEMSS model and parallel GEMSS water quality modeling effort for South Puget Sound

Based on these considerations, the GEMSS model is selected for development for the Quartermaster Harbor Nitrogen Management Study.

3.2.2 Terrestrial Nutrient Loading Model

As noted above, a number of modeling approaches have been used in the Puget Sound region to model terrestrial nutrient loading and linking output to marine (and fresh water) water quality models. These models range from spatially explicit dynamic models of water movement through surface vegetation and subsurface soil (e.g, DHSVM) to less spatially explicit models (e.g., HSPF) to regression approaches that estimate annual, seasonal, or daily loads of constituents of interest to receiving water quality models. The latter approach has been used to develop inputs for the South Puget Sound GEMSS model and is planned to be used to provide inputs to the intermediate and large-scale Puget Sound water quality models (Sackman 2009a and 2009b). For the Hood Canal Dissolved Oxygen Program, terrestrial watershed modeling using DHSVM has also been supplemented with data based and regression based estimates of nitrogen loading to Hood Canal (e.g., Paulson et al. 2007 and Steinberg et al. 2009, respectively)

Given the more limited resources of the Quartermaster Harbor Nitrogen Management Study relative to the Hood Canal Dissolved Oxygen Program, one of the primary considerations is the familiarity of the project modeling team with the models under consideration. This criterion limits the options to HSPF or some type of source loading and/or regression-based loading estimates. Based on these considerations, a data based approach (including regression models) is selected for development for the Quartermaster Harbor Nitrogen Management Study. This approach will provide a relatively transparent accounting of sources including on-site septic systems, livestock, and atmospheric deposition that would be not be within the Quartermaster Harbor study resources to model explicitly in DHSVM, HSPF, or any other spatially explicit or distributed mechanistic model.

4.0. MARINE HYDRODYNAMIC MODEL SETUP

Development of the Quartermaster Harbor hydrodynamic model will consist of three steps:

- Model grid development
- Model setup involving specification of boundary conditions for the selected calibration period
- Calibration and sensitivity analysis

4.1 Grid Development

The grid development and preparation of model input files are part of the model setup and are specific to the modeling system selected. The most recent Puget Sound digital bathymetry data will be used to develop a model with layers with adequate thickness in the vertical (1 to 2 m) to address the highly stratified nature of the harbor. Horizontal grid resolution will be sufficient to capture any opposing flow directions across the harbor entrance and between the inner and outer harbor (~ 10 grid cells). A tradeoff between desired detailed grid resolution and model run time will be considered explicitly in grid development so that the resulting hydrodynamic model will run a simulation of a year in real time in no more than 24 hours of computer time on a desktop computer.

The grid will also be constructed with the intent of using the larger scale South Puget Sound GEMSS model grid to supplement model boundary conditions provided by the Quartermaster Harbor entrance mooring and monthly profiling of temperature and salinity.

4.2 Boundary Conditions and Meteorological Forcing

Tidal elevation at the open boundary will be specified using predictions from PSTIDES – tide predictions generated from the Puget Sound Tide Channel Model. At the water surface, wind stress and heat exchange will be based on available meteorological observations. Meteorological forcing, including air and dew point temperature, wind speed, cloud cover, and solar radiation will be specified using direct measurements collected from the nearest station on Vashon Island and supplemented as needed with data from nearby Sea-Tac International Airport.

The salinity and temperature boundary condition profile at the harbor entrance will be specified using data from a mooring at the harbor entrance and monthly temperature and salinity profiling data. The collection of these data is described in the overall project plan for the Quartermaster Harbor Nitrogen Management Study (King County 2009). The mooring was installed at the entrance to Quartermaster Harbor in 2009. The mooring continuously (15-minute frequency) monitors dissolved oxygen, temperature, salinity, and chlorophyll fluorescence at fixed surface and bottom depths and monitors dissolved nitrate at the surface.

Flow and temperature of Judd and Fischer Creek will be based on continuous gauge records collected during the calibration period. Surface water contributions from the ungauged drainages to the harbor will be estimated by scaling inputs from the gauged basins. Some of these inputs will be represented by distinct inputs (e.g., Mileta Creek), but smaller streams will not be represented explicitly. Estimates of sub-marine ground water inputs will also be develop and provided as a model input.

4.3 Calibration Strategy

Model calibration, described in more detail below, will be conducted by comparing predicted tides, currents, and salinity and temperature profiles predicted by the model to observed data. The process of calibration will consist of steps such as refining the model grid as required, adjusting bottom roughness and friction, and varying tidal phase along the open boundary. Once the model calibration is completed, sensitivity analysis will be performed testing the stability and reliability of the model to a wide range of inputs.

5.0. MARINE WATER QUALITY MODEL SETUP

Development of the marine water quality model will consist of two steps:

- Specification of model boundary conditions
- Calibration and sensitivity analysis

5.1 Boundary Conditions and Meteorological Forcing

In addition to the inflows from Judd and Fischer Creek and other ungauged surface inputs already specified as part of the hydrodynamic model, the water quality model will require inputs for a variety of water quality constituents including:

- Organic phosphorus (particulate and dissolved)
- Dissolved phosphorus (soluble reactive phosphorus)
- Organic nitrogen (particulate and dissolved)
- Ammonia nitrogen
- Nitrate + nitrite nitrogen
- Silicate
- Dissolved oxygen
- Total organic carbon (TOC)
- Dissolved organic carbon (DOC)
- Carbonaceous biochemical oxygen demand (CBOD – estimated from TOC or DOC)
- Specific biomass estimates for the algal species represented in the model (based on chlorophyll or carbon)

In general, these inputs will be based on a combination of observed data, modeling, and literature values. Care will be taken to include or exclude the contribution of algal nutrients and carbon as appropriate for estimating a particular boundary condition or model calibration time series. The development of the water quality boundary conditions is discussed in more detail in the following section on the development of a terrestrial loading model.

Atmospheric loading of nitrogen and phosphorus will be based on regional deposition data following the approach outlined by Paulson et al. (2007) used to develop loading estimates for Hood Canal.

Meteorological forcing will the same as that specified for the marine hydrodynamic model.

Marine boundary conditions will be provided by the harbor entrance mooring and routine monthly water quality profiling described in the Quartermaster Harbor Nitrogen Management Study QAPP (King County 2009).

5.2 Calibration Strategy

Model calibration, described in more detail below, will be conducted by comparing predicted profiles of nutrients, phytoplankton biomass (using chlorophyll *a* as a surrogate), and dissolved oxygen to observed profiles collected from the monthly profiling stations and the marine moorings in the harbor. The approach to calibration will be guided by the experience acquired by Ecology with the South Puget Sound GEMSS model calibration. Once the model calibration is completed, sensitivity analysis will be performed testing the stability and reliability of the model to a wide range of inputs.

6.0. TERRESTRIAL LOADING MODEL

The exact form of the terrestrial loading model can not be specified at this time, but will draw on the experience of researchers involved in the Hood Canal Dissolved Oxygen Program (e.g., Paulson et al. 2007; Simonds *et al*.2008; Steinberg 2009), Dyes and Sinclair Inlet model (May *et al*. 2005), and the South Puget Sound Dissolved Oxygen Study (Roberts *et al.* 2009a). In general, the terrestrial modeling plan is to come up with source specific estimates of nutrient (particularly nitrogen) loading to Quartermaster Harbor. To the extent possible, loading from sub-marine ground water inputs to the harbor will also be estimated using methods found in Pitz (1999) and Simonds *et al*. (2008). These estimates will be based on available local and regional data and where these types of data are not available, literature-based estimates will be used. The terrestrial loading model will be designed to facilitate the development of modeling scenarios that address specific nitrogen management approaches. An report describing initial estimates of direct loading to the harbor has been complete (King County 2010), which will provide a foundation for the development of terrestrial loading estimates for model calibration, evaluation, and scenario development.

7.0. MODEL CALIBRATION AND EVALUATION

7.1 Methods Overview

Once the model setup is completed, the model will be calibrated through comparison with observed data collected in Quartermaster Harbor. The term *calibration* is defined as the process of adjusting the model parameters within physically defensible ranges until the resulting predictions give the best possible match with observed data. In some disciplines, calibration is also referred to as parameter estimation.

Model evaluation is defined as the process used to generate information to determine whether a model and its analytical results are of a quality sufficient to serve as the basis for a decision and whether the model is capable of approximating the real system of interest (USEPA, 2008). In some disciplines, evaluation is also referred to as validation, confirmation, or verification.

To help ensure that the process of model calibration and evaluation remain independent, a subset of the available data will be withheld during model calibration. The withheld data will be used to evaluate the model output. In situations involving data scarcity it may be necessary to use all available data for calibration purposes. The final report will describe those data sets (or subsets thereof) that were used for both calibration and evaluation of the model.

Model calibration is an iterative procedure that is achieved using a combination of best professional judgment and quantitative comparison with a subset of the measured data. For example, matching the water column concentrations of nitrogen compounds will involve adjustment of nitrification and organic nitrogen hydrolysis rates, as well as uptake rates by phytoplankton. Matching the water column concentrations of phosphorus compounds will include adjustment of organic phosphorus decay rate and uptakes rates by phytoplankton. Chlorophyll a data will represent phytoplankton biomass and will be used to adjust algal growth, die-off, respiration, and settling. Finally, phytoplankton growth, re-aeration, and BOD, in combination with nearshore SOD, will be specified to obtain the best match with observed DO data. When possible, direct measurements of the rate constants for key processes will be used to calibrate the model (e.g., maximum growth rates of phytoplankton, half-saturation constants).

Both calibration and evaluation of the model will rely on a combination of quantitative statistics for goodness-of-fit and visual comparison of predicted and observed time series and depth profiles (Krause et al., 2005). This methodology is consistent with the standard practice that has been established for similar modeling programs and other detailed studies. These include the following:

•Hood Canal Dissolved Oxygen Program.

•UW PRISM Modeling Program.

•Budd Inlet Scientific Study (Aura Nova Consultants et al., 1998).

•Deschutes River/Capitol Lake/Budd Inlet Water Quality Study (Roberts et al., 2009a).

•South Puget Sound Dissolved Oxygen Study (Roberts et al., 2009b).

Bias will be assessed by calculating the average residual of paired values [mean(predicted - observed)]. A poor fit between modeled and observed data can sometimes yield a near-zero bias if the positive and negative deviations in a data set are of a similar magnitude. Therefore, measurements of precision will be used to further quantify and refine the goodness-of-fit between the model predictions and observations. Precision will be assessed by calculating the root mean square error (RMSE) of paired values [sqrt(mean((predicted - observed)^2))]. Calibration will aim to decrease both bias and RMSE between predictions and observations, but will predominantly focus on reducing bias.

7.2 Targets and Goals

In general, water quality model calibration begins with hydrodynamic model calibration. Hydrodynamic model calibration targets for this project are an average bias of less than ±10 cm for model vs. observed tidal height, ±1 ^{o}C for temperature, ±1 psu for salinity, and within 10% on average from the observed velocity observations reported in cm/s.

The marine water quality model calibration will focus on representing the overall average DO, chlorophyll, and nutrient concentrations well. Short-term effects of ephemeral events such as storms may not be represented as well. Highest priority will be devoted to describing the DO levels in the late summer and fall months when the lowest levels are expected. The calibration target for DO is a bias as close to zero as possible and a RMSE of less than ±2.0 mg/L for the bulk of the late summer and fall DO data. Ultimately, the model's calibration will need to be sufficient to meet the goal of being a planning-level tool to evaluate proposed nitrogen management strategies.

7.3 Data Use Preferences

Data for model calibration and evaluation will be used in a hierarchal fashion. Preference will be to use data that are coincident in both time and space (i.e., Quartermaster Harbor from 2009 – 2010) to the model simulations. If data are scarce then only spatially coincident data may be considered. Should data or published guidance for a particular parameter value be lacking entirely, then published values from similar aquatic systems may be used. In all cases, best professional judgment will be used for the final determination of what data are used to calibrate and evaluate the model.

8.0. SENSITIVITY AND UNCERTAINTY ANALYSIS

To evaluate model performance and the variability of results, sensitivity and uncertainty analyses will be carried out. Uncertainty can arise from a number of sources that range from errors in the input data used to calibrate the model, to imprecise estimates for key parameters, to variations in how certain processes are parameterized in the model domain. Regardless of the underlying cause, it is good practice to evaluate these uncertainties and reduce them if possible (USEPA, 2008; Taylor, 1997; Beck, 1987).

A model's sensitivity describes the degree to which results are affected by changes in a selected input parameter. In contrast, uncertainty analysis investigates the lack of knowledge about a certain population or the real value of model parameters. Although sensitivity and uncertainty analyses are closely related, uncertainty is parameter-specific, and sensitivity is algorithm-specific with respect to model variables. By investigating the "relative sensitivity" of model parameters, a user can become knowledgeable of the relative importance of parameters in the model. By knowing the uncertainty associated with parameter values and the sensitivity of the model to specific parameters, a user will be more informed regarding the confidence that can be placed in the model results (USEPA, 2008).

During the calibration process, the responsiveness of the model predictions to various assumptions and rate constants specified will be evaluated. The model setup will likely include parameters based on literature recommendations and best professional judgment, and estimates of loads in the absence of data. Specific areas to address with sensitivity and uncertainty analyses include boundary conditions, meteorologic forcing, sediment fluxes, watershed loads, and process rate parameters. Fundamental parameters will be varied by (1) increasing and decreasing by a factor of two or an order of magnitude, and (2) the resulting predictions compared to understand whether a factor has a discernible effect on water quality predictions. The final report will document the parameters that are varied and will identify any parameters that have great uncertainty and strongly influence the results.

9.0. EVALUATION OF MODEL SCENARIOS

After sensitivity analyses have been performed, the calibrated model will be used to evaluate water quality conditions observed in Quartermaster Harbor in 2009 and 2010 and to simulate the effects of various alternative nutrient-loading scenarios. Results from this time period will also be compared to estimated natural background conditions. Natural conditions are characterized by the absence of human impacts on the nutrient-loading and DO regime.

Modeling natural conditions typically involves creating a natural background model run corresponding to the existing conditions model run, except that estimated human influences have been removed as much as possible. Generally, this means removing all point sources and setting tributaries to natural loads. Accurate estimation of pre-development conditions may be difficult, so reasonable estimation methods will need to be developed. One possible strategy would be to set nutrient levels using reference streams/rivers in Puget Sound with the lowest (or nearly the lowest) nutrient levels observed (Sackman 2009a). Some of the parameters may remain unchanged between natural and existing if no information is available to estimate pre-development conditions. The current Quartermaster Harbor boundary condition will initially be assumed to be natural for the purposes of this study.

The scenarios that will be evaluated will be determined at a later time, but will primarily focus on the potential benefit of various nitrogen management scenarios or potential future conditions if no action is taken.

Scenario results will be evaluated both as predicted patterns for that scenario and as differences between the base case (or natural conditions) and any particular scenario.

10.0. MODEL OUTPUT QUALITY (USABILITY) ASSESSMENT

Final assessment of model performance will be conducted and summarized in the final report. This summary will evaluate whether the outcomes have met the project's original objectives. Criteria to be evaluated include whether or not the water quality model:

- Behaves in a manner that is consistent with the current understanding of processes known to affect water quality in the Puget Sound estuary system.
- Realistically reproduces variations in water quality observed on inter-annual, seasonal, and possibly intra-seasonal timescales.

10.1 Reconciliation with User Requirements

This project seeks to identify the sources and quantify the amount of nitrogen entering Quartermaster Harbor from these sources. Furthermore, through modeling and additional special studies, the goal of this project is the development of an understanding of how oxygen concentrations in the harbor respond to current nitrogen loading. If the study determines that the harbor oxygen concentrations are sensitive to nitrogen loading, various nitrogen management strategies will be evaluated using the developed models. Ultimately, the project goal is to identify feasible strategies for nitrogen management on Vashon-Maury Island and provide recommendations to implement those strategies via policy, regulation or programmatic actions, as input to the update of the 2012 King County Comprehensive Plan.

Reports generated for this project will include identification of any data limitations determined through application of the Data Quality Objectives described in the overall project plan (King County 2009). This information will be communicated initially through annual project reports and will be mirrored in subsequent project reports that rely on data with known limitations, including, but not limited to, modeling reports and reports containing recommended updates to decision makers that update the King County Comprehensive Plan.

11.0. ORGANIZATION AND SCHEDULE

11.1 Project Management and Oversight

This project will be managed by King County and includes collaborators from the UWT, Ecology, and the Groundwater Protection Committee. Funding will be provided by the EPA WEI grant described above. In addition to direct grant support, staff time and resources (primarily in the form of field equipment and laboratory services) are also being provided to match a portion of the grant. The project team plans to meet at least quarterly to communicate progress, problems, and plan future activities. Although no formal technical advisory committee has been formed, work plans and products (including this QAPP) will be reviewed by the project team and technical reviewers assigned by EPA Region 10, primarily the EPA Project Monitor assigned to this grant.

11.2 Project Staff list and roles

The modeling component of the project involves staff from King County Departments of Natural Resources and Parks (DNRP) in collaboration with the Washington Dept. of Ecology's Marine Monitoring Unit. Detailed roles and responsibilities are:

Core Project Team:

Curtis DeGasperi–King County DNRP - Project Manager - responsible for: (1) supervising project implementation; (2) coordinating and tracking work, budgets and personnel; (3) preparing and presenting presentations and written reports; and team member for all surface water activities. Curtis will also assist with the selection and development of watershed and QMH water quality models and development of the selected watershed and marine water quality models.

Cooperators:

Skip Albertson - Washington Department of Ecology (Ecology) - Ecology staff will assist with model selection and develop model selected to simulate the hydrodynamics of QMH. Skip will also collaborate on the coupling of the modeled hydrodynamics into the model selected and developed to simulate the effects of N-loadings on dissolved oxygen within QMH in current and BMP scenario conditions.

11.3 Major Activities and Timelines

Table 1 outlines the modeling activities and timelines. This project has three major phases as well as ongoing activities that will occur every year of the study. Modeling activities, other than the development of the modeling QAPP, begin in Phase 2 (2010) of the project.

Table 1. Quartermaster Harbor Nitrogen Management Study Modeling Activities.

Ongoing activities	Timeline	Organization	Description
Phase 1 activities	**Timeline**	**Organization**	**Description**
Modeling QAPP document	2009	All	Write and approve an Modeling Quality Assurance Project Plan (QAPP) that includes documentation of models selected for use in this study
Phase 2 activities	**Timeline**	**Organization**	**Description**
Watershed modeling	2010-2011	King County	Develop nutrient loading model of the contributing basins to QMH, assess the loading and transport of nitrate using both existing information and newly collected data
Marine hydrodynamic modeling	2010	Ecology	Develop selected marine hydrodynamic model of QMH
Marine water quality modeling	2010-2011	King County	Develop selected water quality model of QMH based on calibrated hydrodynamic model
Phase 3 activities	**Timeline**	**Organization**	**Description**
Nitrogen management scenarios	2012	King County /Ecology	Develop set of nitrogen management scenarios. Estimate effectiveness of various nitrogen management scenarios using models.
Modeling report	2012	King County /Ecology	Write report of modeling work completed as part of QMH Nitrogen management study

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