Independent Peer Review of

Review of Available Science for Dissolved Oxygen Impacts in Hood Canal

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Introduction

This documents responds to charge questions developed to focus an independent review of the document entitled, “Review of Available Science for Dissolved Oxygen Impacts in Hood Canal,” dated February 8, 2012, by the U.S. Environmental Protection Agency and the Washington State Department of Ecology. The review was convened by the Puget Sound Institute at the request of the EPA and Ecology and authored by a panel of six, nationally-recognized experts:

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The review panel convened on March 6-7, 2012 in Tacoma, WA. This report first summarizes the panel’s findings, which are then followed by more detailed responses to the individual charge questions.

Summary

The Review Panel reached the following general conclusions.

1. The main characteristics of interest were generally identified in that watershed inputs and marine circulation are critical elements of analysis. However, there is a discrepancy between the spatial and temporal scale implied in the regulation and that captured in the EPA/Ecology report, and elsewhere.
2. The watershed loading of nitrogen (N) presented in the EPA/Ecology report, and elsewhere, is likely to be of a reasonable order of magnitude, but most probably underestimates the actual N load. Refinements could improve the credibility of the estimate, and reduce the uncertainty.
3. Marine circulation was estimated with several variations of a box model; the simple salt balance is preferred as it relies on fewer, poorly characterized parameters. However, these methods were conceptually incorrect as they neglected tidal dispersion, or any other time-varying contribution to salt and N budgets, which may be significant in magnitude.
4. The links between N load → algal biomass → dissolved oxygen (DO) deficit are complex and, in all likelihood non-linear. In addition to inherent errors in estimating marine and anthropogenic N loads, algal biomass, and vertical mixing and lateral transport, these complex links will result in a very large uncertainty in the estimate of the contribution of anthropogenic N to the DO deficit.
5. Data from Hood Canal monitoring buoys provide a valuable opportunity to characterize and estimate DO dynamics. An uncertainty analysis should be performed using data from the monitoring buoys. This analysis would quantify the temporal and spatial variation in DO in Hood Canal and allow researchers to determine the range of potential impacts (from watershed-derived N loads) that would be detectable.
6. It is reasonable to conclude that it is unlikely that human-associated activities currently impact dissolved oxygen concentrations to a magnitude greater than 0.2 mg/L in the *main stem* of the Hood Canal.
7. The evidence supporting the case that anthropogenic N sources can be associated with a DO impact greater than 0.2 mg/L in any specific area of Hood Canal, including Lynch Cove, is not strong. Given both the large natural variability of the Hood Canal system and the inherent uncertainty in translating nutrient loads to dissolved oxygen impacts, the available observational program and analyses may not be capable of detecting a deficit of that magnitude, were it to exist.

Section 1. GENERAL

Question 1a. Does the existing body of work identify the main characteristics of interest relating to dissolved oxygen (DO) conditions and human impacts in Hood Canal and Lynch Cove, or are there critical gaps in the conceptual models and analyses included in the EPA/Ecology report?

Response to 1a.

The main characteristics of interest were generally identified in the analysis in that shoreline inputs and marine circulation are critical elements. However, there is a discrepancy between the spatial and temporal scale implied in the regulation and that captured in the EPA/Ecology report and elsewhere. Background, contextual information provided by EPA and Ecology indicated that, "where natural conditions cause dissolved oxygen levels to fall below threshold concentrations (7.0 mg/L in Hood Canal), Washington standards require that human activities cause less than a 0.2 mg/L impact to dissolved oxygen concentrations *at any time and any location* (emphasis added)." In contrast, the analysis performed to evaluate anthropogenic impacts were on larger spatial and longer temporal scales. The temporal scales were on the order of several months (e.g., summer) to a year; the spatial analyses were performed on watersheds (e.g., entire Hood Canal or Lynch Cove). These large-scale approaches do not, and cannot, capture short-term (e.g., diel) variations in dissolved oxygen, resulting in a conceptual gap between the regulation and the analysis. It is understood that decisions of scale are made during the selection of analytical processes and methods (i.e., a modeler implies scale based on the selection of model grid elements). However, the data indicate that DO impacts might be evident on daily time scales and to a small spatial extent; the analyses are not resolved to match this scale. The scales of variation in areas where a significant deficit is suspected must be established (by moored observations combined with some near-synoptic surveys) in order to design an adequate monitoring program.

A description of the process by which decisions of scale are made would assist in the development of an appropriate observational and analytical program.

Question 1. Have EPA and Ecology come to reasonable conclusions regarding the magnitude of human impacts to DO based on available information for Hood Canal and Lynch Cove?

Question 1b. Is the conclusion that anthropogenic inputs likely do not have an impact on DO (<<0.2 mg/L) in the main stem of Hood Canal supported by available information?

Response to 1b.

After reviewing the available information it is reasonable to conclude that it is unlikely that anthropogenic activities are currently affecting DO to a magnitude greater than 0.2 mg/L in the main stem of the Hood Canal. The primary information supporting this conclusion is the low population density along the shoreline in this area, the calculated values of marine circulation, and the levels of dissolved nitrogen in the marine waters.

Question 1c. Is the conclusion that anthropogenic inputs on DO in Lynch Cove are approaching, but have not definitively exceeded the regulatory threshold of 0.2 mg/L DO, supported by available information?

Response to 1c.

The evidence to support a DO deficit of greater than 0.2 mg/L due to human impacts is not strong. However, detecting an effect of this magnitude and attributing it to human activities would be very difficult in this system. Though the existing data is high quality and the modeling tools have been thoughtfully employed, there is substantial spatial and temporal variability in this system (as shown in the data presented in the EPA/Ecology report, as well as the background data provided by HCDOP and others), which confounds the detection of change. Further, the known limitations in available modeling tools will likely result in an uncertainty in predicting the DO deficits attributed to anthropogenic and/or natural processes that is greater than 0.2 mg/L.

A further refinement of the Monte Carlo analyses, with the rigorous inclusions of the uncertainty of each of the factor components, might give an indication whether anthropogenic impacts of 0.2 mg/L were a central tendency. This analysis would also reveal overall uncertainty, which could be compared to the given threshold of 0.2 mg/L DO.

Question 1d. Can the uncertainty in the human impacts on DO be reduced with the currently available information and tools, as reviewed in the EPA/Ecology report?

Response to 1d.

There is a wealth of data produced by the monitoring buoys along the length of Hood Canal that can provide the much needed, temporally explicit detail of the conditions in the water column. Examples are included in Chapter 1 (see Fig. 6; Newton et al, 2012) and Chapter 3.3 (Devol et al, 2011) of the HCDOP reports. This information was not utilized in a meaningful way to evaluate variability or uncertainty of the approaches, but should be. A proper investigation of the uncertainty of the analyses that were performed would give an indication of the magnitude of impacts that could be detected with the current methods. This analysis may reveal that the uncertainty is greater than required to support regulatory or management decision-making. In such a case further work should be done. In particular, the three dimensional model, if properly validated, could be employed to assess the magnitude of the natural variability and the magnitude of an anthropogenic deficit that could be detected.

Question 1e. What information/tools would be necessary to substantially reduce the uncertainty from a technical and regulatory perspective?

Response to 1e.

It is unlikely that the best available modeling tools are sufficiently precise to resolve human impacts on DO in Hood Canal to the level required by the current regulation. The spatial and temporal variability in many components of the system (population, subsurface denitrification, estuarine circulation, the impacts of logging and red alder N fixation, growth-response, etc.) are difficult to capture individually; propagation of uncertainty is required for a holistic evaluation but was not done.

That being said, several recommendations were made in the individual responses (see below) which we feel would improve these analyses and may lead to a reduction in overall uncertainty of the evaluation.

Section 2. ANTHROPOGENIC NITROGEN LOADING

Question 2a. Do the existing approaches described in the document capture potential anthropogenic nitrogen (N) inputs into Hood Canal? Is the reported range of potential loading supported by existing information?

Response to 2a.

The several papers and the EPA/Ecology report summarizing results are an admirable effort, considering that the sources of data had different purposes and different scopes of space and time. The report seems likely to have the order of magnitude of the watershed-derived nitrogen loads assessed adequately. At the same time, below, we include a number of suggestions that would improve the presentation, and suggest some alternative calculations that would lead to more intellectually compelling, and perhaps improved estimates of anthropogenic nitrogen loads. The suggestions below are a mix of editorial comments and suggestions for new calculations.

Dry deposition reported in Fig. 13, and Paulson et al. (2006) and Steinberg et al. (2010) are substantially lower than those reported from other places, more explanation is needed as to why this region differs markedly from other sites. Papers by Weathers et al. (2006) and by Bowen and Valiela (2001) could be cited for comparisons.

The report shows different estimates for inputs from the Alderbrook resort; it would be helpful to know how these different values were reconciled and a final value was selected.

In several places (pages 22, 23, 28), the report mentions data processing using medians. While this may seem reasonable at first sight, in many instances, such practice leads to considerable underestimates. In particular, groundwater nutrient concentrations are characteristically highly skewed, and a few rare but quite high values are the rule. It turns out that these parcels of high nutrients reach receiving waters, and contribute to nutrient loads. They should not be ignored in estimates of watershed-derived nitrogen loads, and the report ought to deal with estimates that include the high values. If more sophisticated weighting protocols are not used, the use of means is recommended.

A better description of the land covers and practices (include area of logged parcels, whether vegetation is accreting, the extent of agricultural uses, use of lawn fertilizers near-shore) would help provide the context to discussion in pages 24 and ff. It is not self-evident what is meant by “background” (please define).

Some standard way to deal with Total Dissolved Nitrogen (TDN), Dissolved Organic Nitrogen (DON), etc. needs to be consistently used in the EPA/Ecology report and a specific consideration of DON should be included. DON concentrations are usually highly variable, are usually higher than Dissolved Inorganic Nitrogen (DIN) in many waters, but in stark contrast, seem rather low in the Hood Canal ecosystem. More importantly, the bulk of DON may be biologically unavailable (for example, check paper by Kroeger et al. 2006). We recommend focusing on nitrate and ammonium as the data are available and there is a higher degree of certainty with regard to its biological utilization. However, DON still may contribute to biomass production.

DON measurements, and bioassay experiments to determine bioavailability, especially in Lynch Cove, in the summer period would provide useful insight on utilization and potential contribution to biomass production.

There are many places where explicit definitions need to be made. For example, “Human” is too vague a term. Perhaps the authors mean wastewater. Please also define “residential development”, and “natural background” (p. 30).

In Steinberg et al. (2010), the different sources of watershed-derived N inputs were obtained by examining correlations of watershed land uses with N concentrations at the mouth of tributaries draining the watersheds. These estimates of watershed-derived nitrogen are likely to produce results with a large uncertainty (we note that the R^2, the coefficients of determination, were considerably below 0.65, the criterion defined for minimum predictive power of regression models; see Prairie (1996)). The large uncertainty derives from the procedure itself, the land use data entered, as well as the uncertainty implicit in inclusion of all mechanisms involved in transport from watershed and through the receiving stream to the mouth of the tributary. These methods are an unorthodox and unconvincing means of sorting out sources of watershed-derived nitrogen. They should be verified by comparison with more-established methods.

We suggest that the results on watershed inputs in the EPA/Ecology report be checked by a more direct calculation of watershed-derived N loads entering receiving waters, such as is available by use of the NLOAD internet site (see Bowen et al. 2007), applying, for example, NLM and ELM models. This would require that land use, and other data from each of the watersheds draining into Hood Canal.

In general, and specifically for calculating a new set of estimates of N loads, there are some further items that need more clarification:

1. logging releases nitrate to soils and streams, and this phenomenon needs to be added to the calculation, since perhaps half the watershed surface was logged, as discernible in remote images.
2. logged areas then become accreting in terms of nitrogen (red alder, a common successionary species, holds about 3% N in its green parts) so this might be considered as a way N is retained within the watershed.
3. existing data on cover and N release rates from red alder needs to be included in a different way. Red alder grow only on land or on fringes of freshwater wetlands. Any N released by alders thus will necessarily have to cross other environments (soil, littoral shore, freshwater streams) before seeping into estuarine waters. Therefore, losses need to be included in the calculations. It seems inadvisable to simply assume that all fixed N reaches the estuaries.
4. it seems arbitrary to consider only septic systems at certain distances from the coast; many septic systems can potentially contribute N to receiving waters, and need to be included (p. 32). There is a detailed discussion of these N dynamics, distances to be considered, and loss terms involved in septic system plumes in Valiela et al. (1997).
5. distributions of TDN concentrations should be used instead of medians in Table 4.

6. if one expects that within-stream changes in fate of N are important, the watershed exports calculated for each tributary from a model such as NLM should then be input to a model that captures the transformations, sinks, and new inputs during transit in the tributaries. The NLOAD site includes ELM, which would be one such model. On the other hand, if transit times are short, and within-stream changes in N can be assumed as minor, the NLM-derived N loads can be summed for all tributaries as the load to Hood Canal.
7. there were some areas with no tributaries: these contribute N, nonetheless, and can be treated in NLM the same as tributary watersheds, and their N contribution added to obtain the load to Hood Canal.

We expect that most of the revisions we suggested above will result in increased TDN loads compared to those currently in the EPA/Ecology report. This is important because the intent of the EPA/Ecology report was to assess the magnitude of anthropogenic land-derived N sources and their link to water quality in Hood Canal.

Question 2b. Does existing information/data support the decision to set an upper bound on the estimates for shoreline On Site Septic (OSS) loadings to Lower Hood Canal/Lynch Cove based on total groundwater loadings, calculated using measured groundwater N concentrations and estimated groundwater flows from water balance calculations?

Response to 2b.

Several different approaches for estimating N inputs from OSS systems to Lynch Cove were presented in the report. One approach required an estimate of groundwater flow rate and N concentration in groundwater. Another approach estimated N loading via groundwater using per capita estimates.

Only one reliable groundwater flux is presented in the EPA/Ecology report, estimated from a water balance. The estimate was made for Hood Canal, but is also extended to Lynch Cove[1]. The groundwater flux estimated from the water balance seems defensible. Table 12 has a standard deviation around this estimate, but it isn't clear where this standard deviation comes from—is it an inter-annual deviation? This should be made clearer. In Table 12, it is assumed that this flow rate is normally distributed. A justification for this should be provided.

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[1] A literature search (outside of the report) indicates an additional groundwater flow rate estimated from measurements of Rn, Ra, and seepage meters by USGS; however, these estimates are much larger than those obtained from the water balance approach (Swarzinski et al. 2007). Discussion during this review indicated USGS does not trust these estimates and that the results of the paper in ES&T are not correct. Estimates published in a high impact peer review journal should be withdrawn if they are not correct.

A number of N measurements in groundwater were done by different researchers in different areas of the watersheds. Only measurements of discharging groundwater to Lynch Cove seem appropriate to estimate fluxes to Lynch Cove, and these measurements are available – seeps were sampled along Lynch Cove shoreline. However, even this approach is problematic because ‘plumes’ of high N groundwater discharging into Lynch Cove could be missed by the random sampling of seeps. Additionally, it seems that a median value from only freshwater samples from the seeps is considered (Table 4) and used to estimate fluxes. This is problematic because very high N values may be important (the distribution is right skewed). Also, some high N may be found in marine or brackish samples because the leach field could be inundated with marine water during high tides at sites adjacent to Lynch Cove/Hood Canal. The N in the fraction of freshwater in brackish samples could be back-calculated assuming conservative mixing of fresh and marine water. It doesn’t seem appropriate to use N concentrations measured away from the shoreline in GW (from wells within the watershed) to estimate a flux because N may behave non-conservatively along the flow path from the land to the sea – denitrification could be occurring (see Figure 3 in Bowen et al. (2007) for example).

Other techniques for estimating N loading included per capita estimates (number of people per house * N excreted per unit time per capita* number of houses within a buffer * an assumed lost rate of 35%, for example). The number of people was different depending on the buffer used. This estimate represents a ‘worst case scenario’ and an upper bound on the N loading. It may give unrealistically high N loading estimates on an annual basis. Although this technique can be used to estimate seasonal variation in N loading from changing seasonal populations, it does not capture shorter term variation in GW N fluxes that might occur if N is trapped in thin water films in the vadose zone and is flushed by rainfall and subsequently discharged some time later. The timing of the release of N from OSS, relative to timing of marine N inputs to the photic zone may affect whether OSS impacts DO deficit to a greater extent than marine inputs.

The report indicates that the per capita method may overestimate N loading to the system, and favors the measurement-based loading calculations. However, as discussed earlier, the measurement-based loading calculations may under-estimate the loading since measurements may miss high N plumes and also used the median concentrations of N measured, and ignored N concentrations that could be computed from the brackish and marine seep samples.

There are three possibilities to get better, more defensible N loadings:

1. Re-do N loading estimates using a watershed model that considers N sources as a function of land use and cover and accounts for non-conservative behaviors during subsurface transport (as mentioned above).

   → Problems with this: land cover and use data may be available, but transformation rates may not be readily available for the system and subsurface characterization may not be good enough to assign transformation and fate / reaction rates. Also hydraulic conductivities may not be known, and fractures may be present in the ‘cement material’ at depth making subsurface transport complicated.

2. Use the upper estimates of N-loading from per capita estimates. Choose a (environmentally) protective N-loading rate by choosing a large buffer (see map of buffers in the report).
3. Re-examine the measurements of N in the seep data to obtain more N concentrations. Use all the data – back calculate the N in the freshwater component in brackish samples to use those too. Don’t use the median for the estimates of N, instead using the full distribution of N concentrations (what is done in the Monte Carlo Simulation, and include data from the brackish samples).

The most (environmental) protective choice would be (2) perhaps. Uncertainties in (1) may be great. Method (3) may miss some of the large (and time varying) N concentrations. Any estimate should assess the time-varying loading (forced by changes in land use – residents, and physical transport mechanism) and how this covaries with inputs from the marine bottom waters[2].

The probabilistic estimation on page 61 would be affected by our comments. Regarding the tributary inputs, the human inputs may change. For the OSS inputs, these may change as well – in particular, the N concentrations would change. A justification for the choice of using a normal distribution for the tributary inputs and the GW flow should be provided or justified as these would greatly impact the results and the conclusion regarding the human influence on DO deficit.

In addition, we note that there were several general points that could have received more clear exposition.

1. Paragraph on bottom of p. 32 is hard to follow, needs to be re-done…confusing ..full occupancy can’t be just 2.2 persons per dwelling…etc.
2. The EPA/Ecology report presented a number of situations where there were different estimates of variables obtained by different methods and authors. To neutrally assess relative likelihoods for conflicting estimates, the report carried out a Monte Carlo simulation exercise. This approach might be helpful but needs some re-working. For example there are a substantial number of outcomes to the right of the mode in Fig. 20…we are unsure what to make of the values to the right. The inputs need to be better justified and refined using our suggestions. More importantly, there is the question of the relative

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[2] Timing of watershed and marine inputs are likely in phase temporally. Watershed inputs force circulation and thus marine inputs. It would be nice if the report discussed this phasing more.

validity of the outcomes included in the simulation. In a study of whether heads or tails are more likely, we are fairly certain of the validity of the event “heads” and “tails”. We would recommend that the EPA/Ecology report place more effort on obtaining estimates that have as much validity as feasible; many of our suggestions above should help to determine more credible estimates.

3. For several values, several local experts pointed out the strong seasonality of the exports from watersheds. The entire report needs to be gone over, with a view as to how the time steps (month, season, years) are considered in each section, with some thinking as to how different time steps may or may not have important consequences.

Critical analyses for 2.

The following analyses are critical to the completion of this work. Without them it will be difficult to reach supportable conclusions.

- Re-examine the measurements of N in the seep data to obtain more N concentrations. Use a distribution of N concentrations.
- Rework the Monte Carlo analysis with revised input values and also include a consideration of the validity of the outcomes included in the simulation. We would recommend that the EPA/Ecology report place more effort on obtaining estimates that have as much validity as feasible.
- Use distributions of N concentrations from septic systems, or means, and not medians.
- Include all septic systems in the watershed, and not just those within an arbitrary buffer distance to obtain a worst case scenario estimate.
- Compare loads using more well-established models that are based on the biogeochemical rates and hydrologic processes, rather than purely on correlations.

Recommended analysis for 2.

The following analysis will likely improve the reliability of the estimates.

- Include the impacts of logging on release of soils N.
- Include the N accretion/retention from regrowth of logged areas.
- Utilize models such as NLM to capture N loads from tributary watersheds. The ELM model form the NLOAD site (http://nload.mbl.edu/) can capture nutrient transformations during transit.

- Redo N loading estimates using a watershed model that considers N sources as a function of land use and cover and accounts for non-conservative behaviors during subsurface transport (as mentioned above). Lack of information on transformation rates and subsurface condition may make this problematic.
- Delineate links between nutrients, algae, and hypoxia using concentrations as the drivers.
- Include a consideration of the seasonality of the exports from watersheds.

Section 3. MARINE NITROGEN LOADING

Question 3a. Is the reported range of marine N loading described in Devol et al. (2011) supported by various analytical approaches for marine circulation in Hood Canal?

Response to 3a.

None of the approaches used to estimate the range of marine N loading are explained thoroughly and it is strongly recommended that this topic be revisited. The four methods yield quite different estimates for the horizontal salt flux and marine N flux and none are compared to the available direct measurements from the Twanoh mooring. Use of a salt balance approach (the Knudsen relation) to estimate an inflow transport (Method A in Devol et al.) relies on fewer estimated parameters and is, therefore, the recommended methodology. However, more careful attention to the estimate of the layer salinities is needed and uncertainties in the values should be estimated. The choice of the pycnocline depth (really the depth where the mean velocity equals zero) is not strongly defended and yet is of critical importance. Since the model originates from a vertical integral of the horizontal transport, a more appropriate definition of the layer salinity S_1 would use a flux-weighted value, i.e.

$$s_1 = \frac{\int_{h_i}^{0} u\ s\ dz}{\int_{h_i}^{0} u\ dz}$$

, where u is the horizontal velocity, s is salinity, h_i is the depth of the interface between inflow and outflow (see Figure 1), and the denominator is the outward volume flux in the upper layer.

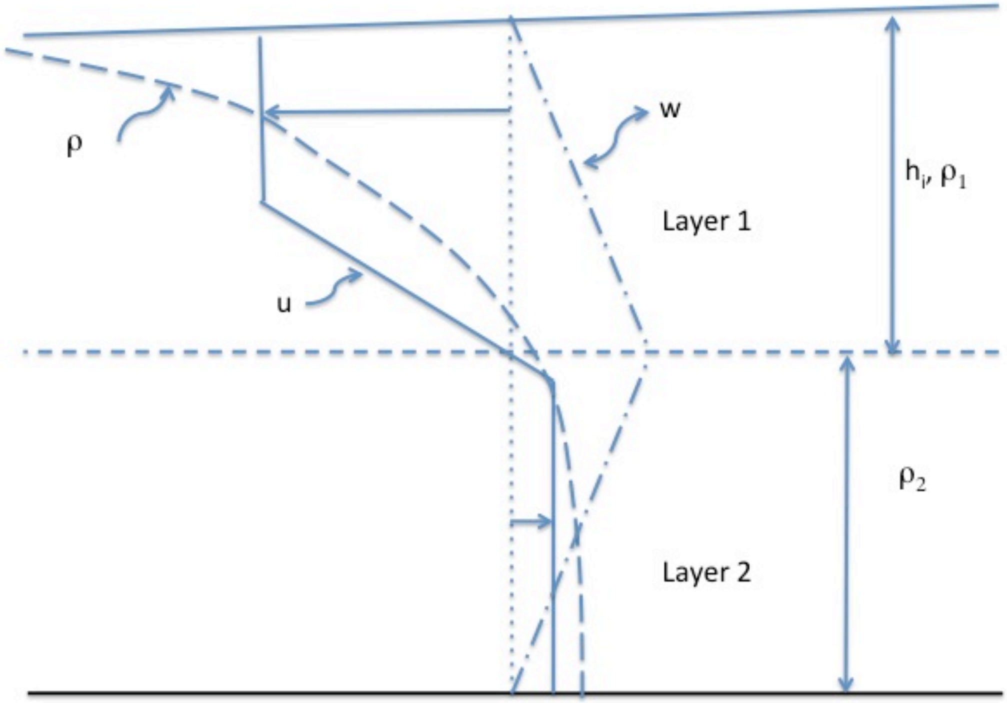

Figure 1 - schematic vertical profiles of horizontal velocity (u), density (ρ) and vertical velocity (w) and the 2-layer formulation used in the report. Note that h_i is the depth of the upper layer and is defined as the vertical location where u=0.

The flux-weighted approach is likely difficult to implement for the surface layer because salinity and velocity change rapidly in the near surface layer. It is our understanding that an extrapolation scheme was used to extend salinity profiles to the surface. A full description of the scheme, an assessment of the uncertainties in layer salinity, and their impact on the fluxes are essential.

We discourage use of the alternative methods for estimating marine N loading for the following reasons:

Method B relies upon an estimate of the area and time mean vertical eddy diffusion coefficient. We do not recommend this approach since there is no basis for selecting the diffusivity value.

Method C seems problematic – it involves a number of uncertain rate estimates to parameterize the effects of denitrification and primary production on the nitrate budget. These undoubtedly add uncertainty to the flux estimates.

Method D is not very well described and may be OK, but it appears that N flux is an input variable in the formulation, and requires many additional parameters. Hence it is a consistency check rather than an estimation technique.

The largest conceptual problem is that all of these formulations neglect tidal dispersion (or any other time-varying contribution to salt and nitrate fluxes). The large tidal range and shallow depths in Lynch Cove suggest that covariance of time-varying velocity and concentration could drive a significant inflow. Using a simple Reynolds decomposition

$$u = \bar{u} + u'$$

$$c = \bar{c} + c'$$

the flux should have two significant contributions

$$\overline{uc} = \overline{u}\,\overline{c} + \overline{u'c'}.$$

These two contributions could vary in magnitude with depth and might even have different signs. The ROMS modeling study finds the eddy flux (u'c') to be equal in magnitude to the mean component. The field observations from Twanoh should be used to estimate these terms. Methods A-C can only capture the mean component; the observations can provide an estimate of the correction needed to account for the total flux.

In summary, it is felt that a revised estimate using Method A that includes uncertainties in a quantitative way, augmented with an estimate of the time-varying contribution based on analysis of existing observations, will yield the most reliable estimate of marine N loading.

Question 3b. In the aggregated model analyses, human impacts to DO at depth in Lower Hood Canal (Lynch Cove) are estimated using the proportion of human nitrogen loadings to total nitrogen loadings. As noted in the EPA/Ecology report, there are two differing views on how to calculate the upward marine nitrogen flux. Is it reasonable for EPA/Ecology to adopt both approaches and conclude that marine nitrogen fluxes affecting DO fall in the resulting range?

Response to 3b.

The presentation of the aggregated model analyses in the summary and the HCDOP report was unclear and imprecise which made it difficult to evaluate the results and to answer definitely if the approach of including both approaches was reasonable. The clarity of the presentation would be improved if the marine N loading estimate were clearly separated from the DO consumption estimate. As it is now written, the presentation of the Devol et al. (2011a) model and Brett (2010a) model emphasize the DO consumption estimates and fail to clearly present how the marine N loading values are estimated. The model equations should be summarized so that the methodology and balances assumed are unambiguous. It appears that to arrive at the marine N loading values the inflow transport from the salt balance was simply multiplied by N concentrations at various depths to define an upward flux of marine nitrogen into a limited region of the upper water column that contains the euphotic zone (where N is consumed). If this interpretation is correct, then the methodology is flawed. Conservation of mass is invoked to argue that the horizontal inflow to Lynch Cove must result in upwelling. However, this results in a vertically-varying vertical velocity that reaches a maximum at the interface between inflow and outflow (see Figure 1). As now applied in the model, a constant value (the maximum value) is used at all depths which over estimates the flux except at the inflow/outflow interface (h_i on Figure 1). Thus the position of the depth surface that defines the base of the euphotic zone relative to the interface must be specified.

If the euphotic zone is deeper than the interface (h_i), then there is an additional pathway for marine nitrogen loading – horizontal advection. Some accounting for this possibility would be wise; the buoy observations can be very helpful in estimating the potential importance of this additional term.

Question 3c. Is the reported range of marine nitrogen loading consistent with model uncertainty?

Response to 3c.

Uncertainty is addressed by providing a range of estimates. The analysis could be improved by more fully exploiting the rich data set that the buoy observations provide to obtain uncertainty estimates that can be propagated through the flux estimation formulae, and to assess the potential errors resulting from the model assumptions. An estimate of uncertainties using a steady balance formulation should be based on the observational uncertainties in estimating the layer salinities. An estimate of the unaccounted time-varying flux should also be based on estimates derived from the observations. Together, these should provide a more defensible range of possible marine nitrogen loadings.

Critical analyses for 3.

The following analyses are critical to the completion of this work. Without them it will be difficult to reach supportable conclusions.

- Provide a more rigorous determination and defense of the selection of inflow/outflow interface depth (note this is a more appropriate definition than pycnocline depth) and explain how layer salinities used in the salt balance formulation of Method A were estimated (i.e. were salinity and velocity profiles extrapolated to the surface? If so, how? Was a flux-weighted salinity computed, or was salinity alone averaged?).
- Include an estimate of tidal dispersion and/or other time-varying aspects of the salt budget in the flux calculations based on the observations from the Twanoh buoy dataset.

Recommended analysis for 3.

The following analysis will likely improve the reliability of the estimates.

- A rigorous uncertainty analysis should be performed by utilizing actual data sets from buoy observations and propagating through flux estimation formulae.
- Utilize buoy observations of flow and N concentrations at different depths to evaluate the potential importance of horizontal advective flux of N into the different vertical compartments defined in the aggregate models.

Section 4. DISSOLVED OXYGEN DEFICIT

Question 4a. There are both spatial and temporal aspects of the DO deficit exhibited in Hood Canal; DO decreases from the mouth to the terminus, and also decreases seasonally (annual maximum in March, annual minimum in late-September) at a given location. The calculation of human impacts using the aggregated model relies on an estimate of the average DO deficit in Lynch Cove over the summer. As noted in the EPA/Ecology report, there are two differing views on the assumptions and methods to calculate this deficit. Is it reasonable for EPA/Ecology to adopt both approaches and conclude that the deficit value falls in the resulting range?

Response to 4a.

1) What are the impacts of anthropogenic N loading on hypoxia potential in the Hood Canal and Lynch Cove?

Exploring the hypothesized N input ➔ phytoplankton production ➔ hypoxia link

External nitrogen (N) inputs have been suggested to be linked to hypoxia potential in the Hood Canal and Lynch Cove, based on the following observations;

1. N is the nutrient that limits phytoplankton primary production (Newton et al., 2012). Therefore, this area is sensitive to anthropogenic N inputs in the spring and summer period.
2. Phytoplankton biomass is a major source of reactive organic matter fueling hypoxia in strongly stratified bottom waters (Steinberg et al., 2010; Devol et al., 2011a).
3. Bottom water DO is potentially influenced by additional N inputs (Devol et al., 2011a, b; Steinberg et al., 2010; Brett 2011a, b).

The conversion of biologically available N inputs into phytoplankton biomass depends on multiple interacting factors, including chemical N form, irradiance, temperature, vertical mixing and lateral transport (i.e. flushing/water residence time). In this regard, there is substantial spatial, seasonal and interannual variability (“noise”) that determines how much of the bioavailable N is converted into phytoplankton biomass.

Phytoplankton community enumeration data from the Hood Canal (Pacific Shellfish Institute, 2008, 2009 progress reports) indicate that the phytoplankton biomass responses to environmental factors (including N inputs) are dominated by episodic blooms. These blooms do not always quantitatively track N inputs, but rather appear to be a response to several environmental factors that contemporaneously control their formation. These physical controlling factors include light, temperature, flushing and residence times, and vertical mixing, in addition to grazing. Therefore, even though N is likely to be the main nutrient that controls (limits) phytoplankton production, it is difficult to develop a strong and predictable direct relationship between N inputs and phytoplankton growth/bloom responses, especially over the time frame (days to weeks) that blooms typically develop, die and sink into bottom waters where they could fuel hypoxia. Primary productivity is relatively high (up to 5 g C/m^2/day) in Lynch Cove throughout the spring and summer with a pronounced peak in production at about

10-12 m (mostly below the pycnocline which is at ~6-8 m (Newton et al. 2012)). The phytoplankton may sink to depth directly or be grazed by zooplankton which would enhance C export via fecal pellets and contribute to remineralization. Presently, there are very few data on the role of zooplankton grazing in controlling the algal blooms and the increase in carbon export to depth.

With respect to the “new” N sources responsible for initiating and sustaining blooms in Hood Canal, marine N inputs (by virtue of being quantitatively very dominant) overwhelm anthropogenic N inputs as shown in Table 9 of the EPA/Ecology report. It is therefore likely that the anthropogenic N signal is swamped as a “new” N source involved in initiating and supporting blooms, even during the spring-fall optimal bloom period. In Lynch Cove, estimates of total loading from human sources range from 5% (Brett 2010a) to 13% (Devol et al. 2011a) with shoreline OSS making up 6% of the total loading. The differences in these estimates are mainly due to the assumptions of the 2 vs. 3 layer approach used in the calculations. Even assuming a worst-case scenario of 13%, not all of the phytoplankton biomass that is produced would sink to depth because of grazing and remineralization of N within the photic zone. Therefore, it is unlikely that this small increase in phytoplankton biomass is exclusively due to anthropogenic N inputs. It is also unlikely that the subsequent decomposition could be detected as a significant signal of the impact on the DO deficit at depth. This statement is in agreement with long term monitoring, which indicates that there is no statistically significant decline in bottom DO in Lynch Cove. Therefore, if there has been an increase in human DIN inputs over the last few decades, it is not evident as a statistically significant, long-term decrease in bottom DO.

Other parameters that could be used to indicate an anthropogenic signal due to N inputs are long term surface winter DIN and long term summer water column integrated chlorophyll (Chl; or at least surface Chl) concentrations. Data should be explored to see if there are any long time series that show any significant anthropogenic signal. In addition, if water column respiration rates had been available, this could have provided an estimate of how much remineralization of N was occurring in the water column, as it is suspected that N remineralization plays an additional role in maintaining phytoplankton production, especially in N deplete near-surface waters.

Lastly, the phytoplankton taxa that tend to bloom in the Hood Canal system are not particularly harmful from toxicity and food web disruption perspectives (i.e. they are dominated by diatoms, and non-HAB dinoflagellates; c.f. Newton et al., 2011). It is likely that these taxa are readily grazed by crustacean zooplankton and potentially other invertebrates (larvae). Aside from being implicated as an organic C source fueling hypoxia, it is not anticipated that other harmful effects of such blooms might currently be expected.

Evaluating the magnitude of marine vs. anthropogenic N sources

Several budgetary and modeling studies have evaluated the overall importance and potential ecological effects of anthropogenic nitrogen loading on hypoxia potentials in the Hood Canal (Paulson et al. 2006; Brett 2010a,b; Richey et al. 2010; Steinberg et al. 2010; Devol et al., 2011a,b). Dominant anthropogenic N sources in the Hood Canal watershed and the air-shed include: tributary loading, onsite septic systems, red alder communities (considered anthropogenic because their diazotrophic growth has been promoted by forest clearing), wastewater treatment plant discharge, groundwater, and atmospheric deposition. These sources were compared to offshore marine (natural) N inputs and their influence as N source supporting algal production (which was considered a major “fuel” for hypoxia) was examined seasonally.

Steinberg et al. (2010) estimated the relative contribution of watershed and marine nitrogen loadings to the surface layer of Lynch Cove (LC) and Hood Canal (HC) as a whole. They estimated marine upwelling flows were paired with bottom layer average TDN concentrations to derive an annual average loading to the surface layer, which Steinberg et al. (2010) defined as the top 5 m in LC and 9 m in the rest of HC. The TDN loading for central HC (39,000 metric tons TDN per year) generally agreed with the upper range of estimates by Paulson et al. (2006). Steinberg et al. (2010) then compared this marine loading to the loadings for watershed discharges, rainfall, and dry deposition. The annual average contribution of marine upwelling to surface layer TDN loadings was estimated at 98% for central Hood Canal, similar to the upper range of Paulson et al. (2006).

The TDN concentrations in LC tributaries are 2-3 times greater than concentrations in HC tributaries due to a higher percentage contribution from red alder and residential development (Steinberg et al. 2010; Richie et al. 2010). With regard to a specific anthropogenic N source of concern, OSS, using conservative estimates, Steinberg et al., (2010) estimated that OSS loadings contribute at most 0.5% of the total nitrogen loading to the surface layer of central HC. This estimate, while on the low side is reasonably close to those of Paulson et al. (2006), Brett (2010a, b), Richey et al. (2010), which are all in the range of 0.5 to 2%. If these comparisons are made for LC, a segment of HC that is most prone to upstream anthropogenic N enrichment, the relative contribution of OSS to total N load is substantially higher, ranging up to 6% (Devol et al. 2011a,b).

Given fluctuations (and hence variability) in N loading due to variable amounts of rainfall, variations in influx of marine N inputs, as well as variability of OSS and other anthropogenic discharges, the anthropogenic “signal” in terms of relative contributions to the total N budgets of the HC and specific regions most susceptible to anthropogenic N inputs (e.g., LC), is quite low and likely to be in the statistical “noise” range. Furthermore, the translation of N inputs into hypoxia potential is at best indirect, and at worst impossible to verify and quantify, because it depends on the assimilation of these N sources by phytoplankton, the growth and bloom potentials all of which are influenced by multiple environmental factors (in addition to N), which can vary substantially in time and space.

2) Calculation of the O_2 deficit for Lynch Cove

DO impacts during the summer period were estimated with aggregate and ROMS biogeochemical models. Two approaches were used in the aggregate model calculations.

Brett (2010a) used a 2-layer model and determined that the DO below 11 m was 1.1 mg/L less than at Hoodsport and using the Steinberg et al. (2010) estimate of 4-8% of total N loading from OSS, they estimated that the DO impact from septic systems in LC was 0.07 mg/L. In contrast, Devol et al. (2011a) used a 3-layer model and higher estimates of OSS loading from Richie et al. (2010) and incorporated a 25-day travel time between LC and HC and estimated a higher DO deficit of 0.24-0.6 mg/L (Table 11 in EPA/Ecology report). The biggest factor causing the difference in the two estimates was the depth range used in the data analysis. In subsequent discussions by the Review Committee, there was agreement that the simpler 2-layer model was preferred (H. Seim & J. O'Donnell pers. comm.; see above).

Devol et al. (2011a) suggested that water from LC flowed out and into HC at 20-30 m and that this low DO water could contribute to the low DO at Hoodsport that was associated with fish kills. However, an excellent monthly time series of buoy and ACDP data from June to Sept, 2006, strongly suggested that low DO deep water in HC is pushed up near the surface by heavier inflowing water from Admiralty Inlet. References provided in the EPA/Ecology report included calculations demonstrating that even if the 20 m water from LC reaches Hoodsport, this volume of water is an order of magnitude less in volume than water pushed up from depth at Hoodsport. The evidence that low DO water from LC makes a contribution to fish kills at Hoodsport is weak.

A recalculation of the marine N input using the 2-layer model (as suggested by H. Seim & J. O'Donnell) will assist in alleviating the 3-fold discrepancy between the marine loading estimates (Brett 2010a = 33.1 MT/mon vs. Devol et al. 2011a = 11.9 MT/mon). If the 2-layer model calculation by Brett (2010a) is a more accurate estimate of the marine N loading, then the anthropogenic N signal will be a smaller percent of total N loading and not likely to be discernible over the variability or 'noise' levels. The probabilistic assessment that there is a 70% chance that the impact of anthropogenic N loading on DO is <0.2 mg/L was done by assessing the uncertainly of the TDN loading components estimated by the equation on pg 61 of the EPA/Ecology report. In addition, the probabilistic results produced by Monte Carlo trials, is actually highly variable because of the large errors associated with each term in the equation. Therefore this 70% estimate should be interpreted/used with caution.

In summary, because of the complex, and in all likelihood non-linear, links between the N load → algal biomass → O_2 deficit, the uncertainty in the quantification of marine and anthropogenic N loads, algal biomass, vertical mixing and lateral transport, this will produce a very large uncertainty in the estimate of the contribution of anthropogenic N to the O_2 deficit.

There is a need for better temporal and spatial coverage in Lynch Cove in summer. Sources of uncertainty and useful additional data for assessing the magnitude and sources that are linked with the DO deficit include:

- Primary production (using stoichiometry to relate N inputs to C production linked to O_2 consumption)

- Water column and sediment respiration rates and N regeneration estimates
- Nitrification and denitrification rates
- OSS inputs – reduce the uncertainty in these estimates
- Zooplankton biomass and grazing
- Carbon flux estimates from sediment trap deployment
- Sediment oxygen demand estimates
- Time series of surface winter DIN to determine if there has been an increasing trend
- Bioavailability of dissolved organic N inputs using bioassay experiments in summer
- Time series of summer water column integrated Chl *a* to determine if there has been any long term increase, especially in Lynch Cove
- At any one time, phytoplankton cells respond to nutrient concentrations, not mass estimates: links between nutrients, algal growth response, and hypoxia would therefore seem best delineated using concentrations as the drivers
- On longer-term (weekly to seasonal) scales, nutrient loading is a useful driver and determinant of phytoplankton community structure and functional responses

Critical analyses for 4a:

The following analyses are critical to the completion of this work. Without them it will be difficult to reach supportable conclusions.

Recommended analysis for 4a:

The following analysis will likely improve the reliability of the estimates.

- Evaluate long-term trends in surface water winter DIN and/or summer water column integrated Chl (or at least surface Chl) concentrations to see if there is any significant anthropogenic signal.
- Use water column respiration rates to estimate of how much remineralization of N occurs in the water column.
- Primary productivity to assess carbon production and accompanying carbon flux rates from sediment trap deployment
- Denitrification and nitrification rates and bioavailability of DON for N budget analysis
- Since an anthropogenic signal will be most easily detectible in Lynch Cove, a better coordinated and more intensive temporal and spatial sampling program should be set up to assess the N budget, C production and export and DO utilization and export of low DO bottom water to the Hoodsport area.

- Recalculate the marine N input utilizing the refined two-box model.

Section 5. LINES OF EVIDENCE

Question 5. Based on the existing status of the modeling and assessment work, is it reasonable to give the aggregated model calculations and ROMS model estimates equal weight in estimating summer DO impacts in Lynch Cove?

Response to 5.

When there are estimates of a parameter that were obtained using different approaches then a weighted average could be computed with weights proportional to the inverse of the uncertainties. At the moment, the uncertainties of the various approaches are not available so the relative merit of the estimates can't be established.

As described above (see response to 3a) we recommend that a single modeling approach be utilized as the estimates of many parameters are only poorly supported; method A is preferred.

The ROMS approach has the potential to be very useful since it can resolve both the spatial structure of the flow and the response to synoptic scale variability. Once the mean salinity and temperature fields, and the response to synoptic scale fluctuations can be simulated, the skill at explaining the inter-annual variations of meteorological forcing should be assessed. Finally, the ecological dynamics should be critically compared to observations. There appears to be production and respiration rate data, but the model has not been shown to reproduce these and it is critical that it does for the nitrate fluxes to be accurate. When that is done the predictions for the impact of the anthropogenic will be more reliable.

Critical analyses for 5:

The following analyses are critical to the completion of this work. Without them it will be difficult to reach supportable conclusions.

- A comparison of the modeled production and respiration rate data with observations is needed to demonstrate some level of model skill in ecological dynamics.

Recommended analysis for 5:

The following analysis will likely improve the reliability of the estimates.

- Apply the ROMS model in a rigorous study of flow structure and response to external forcings, incorporating ecological dynamics.

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Charge Questions

The questions are meant to focus and direct the review of the document entitled, "Review and Synthesis of Available Information to Estimate Human Impacts to Dissolved Oxygen in Hood Canal," by the EPA and Washington State Department of Ecology dated February 8, 2012.

1. GENERAL

a. Does the existing body of work identify the main characteristics of interest relating to dissolved oxygen (DO) conditions and human impacts in Hood Canal and Lynch Cove, or are there critical gaps in the conceptual models and analyses included in the EPA/Ecology report?
b. Have EPA and Ecology come to reasonable conclusions regarding the magnitude of human impacts to DO based on available information for Hood Canal and Lynch Cove?
    ii. Is the conclusion that anthropogenic inputs likely do not have an impact on DO (<<0.2 mg/L) in the main stem of Hood Canal supported by available information?
    iii. Is the conclusion that anthropogenic inputs on DO in Lynch Cove are approaching, but have not definitively exceeded the regulatory threshold of 0.2 mg/L DO, supported by available information?
c. Can the uncertainty in the human impacts on DO be reduced with the currently available information and tools, as reviewed in the EPA/Ecology report?
d. What information/tools would be necessary to substantially reduce the uncertainty from a technical and regulatory perspective?

2. ANTHROPOGENIC NITROGEN LOADING

a. Do the existing approaches described in the document capture potential anthropogenic nitrogen (N) inputs into Hood Canal? Is the reported range of potential loading supported by existing information?
b. Does existing information/data support the decision to set an upper bound on the estimates for shoreline OSS loadings to Lower Hood Canal/Lynch Cove based on total groundwater loadings, calculated using measured groundwater N concentrations and estimated groundwater flows from water balance calculations?

3. MARINE NITROGEN LOADING

a. Is the reported range of marine N loading described in Devol et al. (2011) supported by various analytical approaches for marine circulation in Hood Canal?
b. In the aggregated model analyses, human impacts to DO at depth in Lower Hood Canal (Lynch Cove) are estimated using the proportion of human nitrogen loadings to total

nitrogen loadings. As noted in the EPA/Ecology report, there are two differing views on how to calculate the upward marine nitrogen flux. Is it reasonable for EPA/Ecology to adopt both approaches and conclude that marine nitrogen fluxes affecting DO fall in the resulting range?

c. Is the reported range of marine nitrogen loading consistent with model uncertainty?

4. DISSOLVED OXYGEN DEFICIT

a. There are both spatial and temporal aspects of the DO deficit exhibited in Hood Canal; DO decreases from the mouth to the terminus, and also decreases seasonally (annual maximum in March, annual minimum in late-September) at a given location. The calculation of human impacts using the aggregated model relies on an estimate of the average DO deficit in Lynch Cove over the summer. As noted in the EPA/Ecology report, there are two differing views on the assumptions and methods to calculate this deficit. Is it reasonable for EPA/Ecology to adopt both approaches and conclude that the deficit value falls in the resulting range?

5. LINES OF EVIDENCE

a. Based on the existing status of the modeling and assessment work, is it reasonable to give the aggregated model calculations and ROMS model estimates equal weight in estimating summer DO impacts in Lynch Cove?