

1 Independent Peer Review of

2  
3 *Review of Available Science for Dissolved*  
4 *Oxygen Impacts in Hood Canal*  
5  
6

7 23 May 2012

8 **Report Authors:**

9 Dr. Alexandria Boehm, Stanford University

10 Dr. Paul Harrison, University of British Columbia

11 Dr. James O'Donnell, University of Connecticut

12 Dr. Hans Paerl, University of North Carolina at Chapel Hill

13 Dr. Harvey Seim, University of North Carolina at Chapel Hill

14 Dr. Ivan Valiela, Marine Biological Laboratory, Woods Hole

15  
16 **For the Puget Sound Institute:**

17 Dr. C. Andrew James

18 Dr. Joel Baker

19  
20  
21 **PUGET SOUND INSTITUTE**

**W** UNIVERSITY of WASHINGTON

22 **Introduction**

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

28 Dr. Alexandria Boehm, Stanford University

29 Dr. Paul Harrison, University of British Columbia

30 Dr. James O’Donnell, University of Connecticut

31 Dr. Hans Paerl, University of North Carolina at Chapel Hill

32 Dr. Harvey Seim, University of North Carolina at Chapel Hill

33 Dr. Ivan Valiela, Marine Biological Laboratory, Woods Hole

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

37

38 **Summary**

39 The Review Panel reached the following general conclusions.

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

72

73

74 **Section 1. GENERAL**

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

79 **Response to 1a.**

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

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

101

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

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

108

109

110 **Response to 1b.**

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

116

117 **Question 1c. Is the conclusion that anthropogenic inputs on DO in Lynch Cove are**  
118 **approaching, but have not definitively exceeded the regulatory threshold of**  
119 **0.2 mg/L DO, supported by available information?**

120 **Response to 1c.**

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

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

134

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

138 **Response to 1d.**

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

148 dimensional model, if properly validated, could be employed to assess the magnitude of the  
149 natural variability and the magnitude of an anthropogenic deficit that could be detected.

150

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

153 **Response to 1e.**

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

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

163

164

165 **Section 2. ANTHROPOGENIC NITROGEN LOADING**

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

169 **Response to 2a.**

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

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

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

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

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

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

## 2 - Anthropogenic Nitrogen Loading

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

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

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

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

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

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



## 2 - Anthropogenic Nitrogen Loading

244 6. if one expects that within-stream changes in fate of N are important, the watershed exports  
245 calculated for each tributary from a model such as NLM should then be input to a model  
246 that captures the transformations, sinks, and new inputs during transit in the tributaries.  
247 The NLOAD site includes ELM, which would be one such model. On the other hand, if transit  
248 times are short, and within-stream changes in N can be assumed as minor, the NLM-derived  
249 N loads can be summed for all tributaries as the load to Hood Canal.

250 7. there were some areas with no tributaries: these contribute N, nonetheless, and can be  
251 treated in NLM the same as tributary watersheds, and their N contribution added to obtain  
252 the load to Hood Canal.

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

257

258

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

264 **Response to 2b.**

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

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

---

<sup>1</sup> 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.

## 2 - Anthropogenic Nitrogen Loading

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

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

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

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

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

309

310 → Problems with this: land cover and use data may be available, but transformation rates

## 2 - Anthropogenic Nitrogen Loading

311 may not be readily available for the system and subsurface characterization may not be  
312 good enough to assign transformation and fate / reaction rates. Also hydraulic  
313 conductivities may not be known, and fractures may be present in the 'cement material' at  
314 depth making subsurface transport complicated.

315 2. Use the upper estimates of N-loading from per capita estimates. Choose a  
316 (environmentally) protective N-loading rate by choosing a large buffer (see map of buffers  
317 in the report).

318 3. Re-examine the measurements of N in the seep data to obtain more N concentrations. Use  
319 all the data – back calculate the N in the freshwater component in brackish samples to use  
320 those too. Don't use the median for the estimates of N, instead using the full distribution of  
321 N concentrations (what is done in the Monte Carlo Simulation, and include data from the  
322 brackish samples).

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

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

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

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

---

<sup>2</sup> 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.

## 2 - Anthropogenic Nitrogen Loading

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

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

354

355

### 356 **Critical analyses for 2.**

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

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

370

371

### 372 **Recommended analysis for 2.**

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

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

## 2 - Anthropogenic Nitrogen Loading

- 379 • Redo N loading estimates using a watershed model that considers N sources as a  
380 function of land use and cover and accounts for non-conservative behaviors during  
381 subsurface transport (as mentioned above). Lack of information on transformation  
382 rates and subsurface condition may make this problematic.
- 383 • Delineate links between nutrients, algae, and hypoxia using concentrations as the  
384 drivers.
- 385 • Include a consideration of the seasonality of the exports from watersheds.
- 386

387 **Section 3. MARINE NITROGEN LOADING**

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

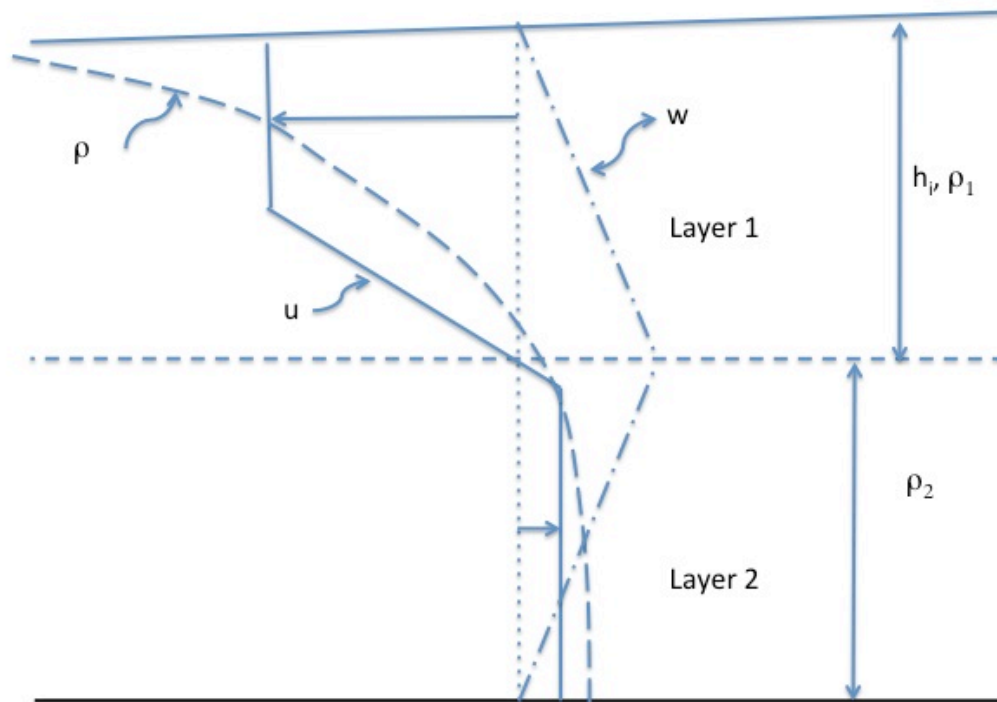
391 **Response to 3a.**

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

$$S_1 = \frac{\int_{h_i}^0 u s \, dz}{\int_{h_i}^0 u \, dz}$$

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

### 3 - Marine Nitrogen Loading



405

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

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

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

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

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

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

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

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

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

428 the flux should have two significant contributions

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

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

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

438

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

445 **Response to 3b.**

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



461 value) is used at all depths which over estimates the flux except at the inflow/outflow interface  
462 ( $h_i$  on Figure 1). Thus the position of the depth surface that defines the base of the euphotic  
463 zone relative to the interface must be specified.

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

468

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

471 **Response to 3c.**

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

480

481

482 **Critical analyses for 3.**

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

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

493

494

495 **Recommended analysis for 3.**

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

- 497
- 498
- 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.
- 499
- 500
- 501

502

503

504 **Section 4. DISSOLVED OXYGEN DEFICIT**

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

514 **Response to 4a.**

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

517 **Exploring the hypothesized N input → phytoplankton production → hypoxia link**

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

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

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

531 Phytoplankton community enumeration data from the Hood Canal (Pacific Shellfish Institute,  
532 2008, 2009 progress reports) indicate that the phytoplankton biomass responses to  
533 environmental factors (including N inputs) are dominated by episodic blooms. These blooms do  
534 not always quantitatively track N inputs, but rather appear to be a response to several  
535 environmental factors that contemporaneously control their formation. These physical  
536 controlling factors include light, temperature, flushing and residence times, and vertical mixing,  
537 in addition to grazing. Therefore, even though N is likely to be the main nutrient that controls  
538 (limits) phytoplankton production, it is difficult to develop a strong and predictable direct  
539 relationship between N inputs and phytoplankton growth/bloom responses, especially over the  
540 time frame (days to weeks) that blooms typically develop, die and sink into bottom waters  
541 where they could fuel hypoxia. Primary productivity is relatively high (up to 5 g C/m<sup>2</sup>/day) in  
542 Lynch Cove throughout the spring and summer with a pronounced peak in production at about

543 10-12 m (mostly below the pycnocline which is at ~6-8 m (Newton et al. 2012)). The  
544 phytoplankton may sink to depth directly or be grazed by zooplankton which would enhance C  
545 export via fecal pellets and contribute to remineralization. Presently, there are very few data on  
546 the role of zooplankton grazing in controlling the algal blooms and the increase in carbon  
547 export to depth.

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

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

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

579

#### 580 **Evaluating the magnitude of marine vs. anthropogenic N sources**

581 Several budgetary and modeling studies have evaluated the overall importance and potential  
582 ecological effects of anthropogenic nitrogen loading on hypoxia potentials in the Hood Canal  
583 (Paulson et al. 2006; Brett 2010a,b; Richey et al. 2010; Steinberg et al. 2010; Devol et al.,

584 2011a,b). Dominant anthropogenic N sources in the Hood Canal watershed and the air-shed  
585 include: tributary loading, onsite septic systems, red alder communities (considered  
586 anthropogenic because their diazotrophic growth has been promoted by forest clearing),  
587 wastewater treatment plant discharge, groundwater, and atmospheric deposition. These  
588 sources were compared to offshore marine (natural) N inputs and their influence as N source  
589 supporting algal production (which was considered a major “fuel” for hypoxia) was examined  
590 seasonally.

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

601 The TDN concentrations in LC tributaries are 2-3 times greater than concentrations in HC  
602 tributaries due to a higher percentage contribution from red alder and residential development  
603 (Steinberg et al. 2010; Richie et al. 2010). With regard to a specific anthropogenic N source of  
604 concern, OSS, using conservative estimates, Steinberg et al., (2010) estimated that OSS loadings  
605 contribute at most 0.5% of the total nitrogen loading to the surface layer of central HC. This  
606 estimate, while on the low side is reasonably close to those of Paulson et al. (2006), Brett  
607 (2010a, b), Richey et al. (2010), which are all in the range of 0.5 to 2%. If these comparisons are  
608 made for LC, a segment of HC that is most prone to upstream anthropogenic N enrichment, the  
609 relative contribution of OSS to total N load is substantially higher, ranging up to 6% (Devol et al.  
610 2011a,b).

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

620

621

## 622 2) Calculation of the O<sub>2</sub> deficit for Lynch Cove

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

625 Brett (2010a) used a 2-layer model and determined that the DO below 11 m was 1.1 mg/L less  
626 than at Hoodspout and using the Steinberg et al. (2010) estimate of 4-8% of total N loading from  
627 OSS, they estimated that the DO impact from septic systems in LC was 0.07 mg/L. In contrast,  
628 Devol et al. (2011a) used a 3-layer model and higher estimates of OSS loading from Richie et al.  
629 (2010) and incorporated a 25-day travel time between LC and HC and estimated a higher DO  
630 deficit of 0.24-0.6 mg/L (Table 11 in EPA/Ecology report). The biggest factor causing the  
631 difference in the two estimates was the depth range used in the data analysis. In subsequent  
632 discussions by the Review Committee, there was agreement that the simpler 2-layer model was  
633 preferred (H. Seim & J. O'Donnell pers. comm.; see above).

634 Devol et al. (2011a) suggested that water from LC flowed out and into HC at 20-30 m and that  
635 this low DO water could contribute to the low DO at Hoodspout that was associated with fish  
636 kills. However, an excellent monthly time series of buoy and ACDP data from June to Sept,  
637 2006, strongly suggested that low DO deep water in HC is pushed up near the surface by  
638 heavier inflowing water from Admiralty Inlet. References provided in the EPA/Ecology report  
639 included calculations demonstrating that even if the 20 m water from LC reaches Hoodspout,  
640 this volume of water is an order of magnitude less in volume than water pushed up from depth  
641 at Hoodspout. The evidence that low DO water from LC makes a contribution to fish kills at  
642 Hoodspout is weak.

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

654 In summary, because of the complex, and in all likelihood non-linear, links between the N load  
655 → algal biomass → O<sub>2</sub> deficit, the uncertainty in the quantification of marine and  
656 anthropogenic N loads, algal biomass, vertical mixing and lateral transport, this will produce a  
657 very large uncertainty in the estimate of the contribution of anthropogenic N to the O<sub>2</sub> deficit.

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

- 661 • Primary production (using stoichiometry to relate N inputs to C production linked to O<sub>2</sub>  
662 consumption)

#### 4 – Dissolved Oxygen Deficit

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

678

679

#### 680 **Critical analyses for 4a:**

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

683

684

#### 685 **Recommended analysis for 4a:**

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

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

#### 4 – Dissolved Oxygen Deficit

- 699       • Recalculate the marine N input utilizing the refined two-box model.  
700



701 **Section 5. LINES OF EVIDENCE**

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

705 **Response to 5.**

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

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

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

720

721

722 **Critical analyses for 5:**

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

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

727

728 **Recommended analysis for 5:**

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

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

732

## References

- Bowen, J.L., and I. Valiela. 2001. Historical changes in atmospheric nitrogen deposition to Cape Cod, Massachusetts. *Atmos. Environ.* 35: 1039-1051.
- Bowen, J. L. , J. M. Ramstack, S. Mazzilli, and I. Valiela. 2007. NLOAD: An interactive, web-based modeling tool to predict nitrogen loads and concentrations in estuaries, and to explore options for nitrogen management. *Ecol. Appl* 17:S17-S30.
- Bowen, J. L., K. D. Kroeger, G. Tomasky, W. J. Pabich, M. L. Cole, R. H. Carmichael, and I. Valiela. 2007. A review of land-estuary coupling by groundwater discharge of nitrogen to New England estuaries: Mechanisms and effects. *Appl. Geochem.* 22:175-191.
- Brett, M. 2010a. Responses by Mike Brett to Hood Canal Coordinating Council (HCCC) science questions. HCCC Technical Advisory Committee. Full document listed below under HCCC 2010. September 29, 2010.
- Brett, M. 2010b. Memorandum to Hood Canal Coordinating Council Technical Advisory Committee re: responses to HCCC science questions. University of Washington, Department of Civil and Environmental Engineering. October 5, 2010.
- Devol, A., Newton, J., Bassin, C., Banas, N., Kawase, M., Ruef, W., Bahng, B., and Warner, M. 2011a. Determining nitrogen loads to lower Hood Canal and effect on oxygen (Draft). HCDOP report Chapter 3, Section 4. May 10, 2011.
- Devol, A., Newton, J., Ruef, W., and Smith, C. 2011b. High Frequency Marine Observation in Hood Canal. HCDOP report Chapter 3, Section 3. April 2011.  
<http://www.hoodcanal.washington.edu/documents/document.jsp?id=2995>.
- Kroeger, K. D., M. L. Cole, and I. Valiela. 2006. Groundwater-transported dissolved organic exports from coastal watersheds. *Limnol. Oceanogr.* 51:2248-2261.
- Newton, J., Bassin, C., Parker-Stetter, S., Horne, J. 2011c. Integrated Assessment and Modeling Report. Chapter 4. Biota. Hood Canal Dissolved Oxygen Program. March 2011.  
<http://www.hoodcanal.washington.edu/documents/document.jsp?id=3002>
- Newton, J., Bassin, C, and Middleton. 2012. Draft Chapter 3.6 Marine phytoplankton production in Hood Canal. Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Report.
- Paulson, A., Konrad, C., Frans, L., Noble, M., Kendall, C., Josberger, E., Huffman, R., and Olsen, T. 2006. Freshwater and saline loads of dissolved inorganic nitrogen to Hood Canal and Lynch Cove, Western Washington. USGS Scientific Investigations Report 2006–5106,  
<http://www.pubs.usgs.gov/sir/2006/5106/>.
- Prairie, Y. T. 1996. Evaluating the power of regression models. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 490-492.
- Richey, J., Brett, M., Steinberg, P., Bechtold, J., Porensky L., Osborne, S., Constans, M., Hannafious, D., and Sheibley, R. 2010. Integrated Assessment & Modeling Study Report.

Chapter 2: Watershed. Hood Canal Dissolved Oxygen Program.

[www.hoodcanal.washington.edu/documents/HCDOP/PUB/hcdop\\_iam\\_watershed\\_ch\\_2.pdf](http://www.hoodcanal.washington.edu/documents/HCDOP/PUB/hcdop_iam_watershed_ch_2.pdf).

Steinberg, P.D, Brett, M.T., Bechtold, J.S., Richey, J.E., Porensky L.M., Smith, S.N 2011. The influence of watershed characteristics on nitrogen export to and marine fate in Hood Canal, Washington, USA. *Biogeochemistry*, 106:415-433, DOI: 10.1007/s10533-010-9521-7.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. *Ecol. Appl.* 7:358-380.

Weathers, K. C., S. M. Simkin, G. M. Lovett, et al. 2006. Empirical modeling of atmospheric deposition in mountainous landscapes. *Ecol. Appl.* 16:1590-1607.

DRAFT

## 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 ( $\ll 0.2$  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?