# Appendix I. Sediment Oxygen Demand

A variety of physical and biogeochemical processes act on organic matter that settles to the sediments. Microbes decompose the organic matter, consuming oxygen. Benthic organisms rework the sediments in a process known as bioturbation. Decomposition and oxidation of organic matter transforms nutrients, releasing them back to the water column. Sediment oxygen levels decline from bottom water concentrations to near zero within a few millimeters to centimeters of the water-sediment interface, which produces strong gradients. These gradients contribute to diffusion into the sediments as oxygen is used to fuel decomposition of organic matter, exerting a sediment oxygen demand (SOD) on the water column.

The processes that control sedimentary organic matter decomposition and SOD are complex and varied, including organic particulate deposition rate and composition, electron acceptor availability, and benthic community composition (Arndt et. al., 2013). More work is needed in the Puget Sound to characterize organic carbon deposition rates, particularly at the vicinity of river mouths and in sheltered areas such as inlets.

It is noteworthy that adversely affected benthic communities were found in inlets and bays throughout Puget Sound (Weakland et. al., 2018). Model predictions show that it is at these locations where SOD is the highest. Organic carbon of terrestrial origin, or allochthonous carbon, may play a significant role in these areas. A recent comparison (Figueroa-Kaminsky, 2018) of water column particulate organic carbon (POC) observations and loadings currently employed for modeling purposes suggests that POC loads, based on monthly observations, may significantly underpredict river loadings during high flow events or dam releases. Thus, improved observations may lead to further loading improvements, which may change the model's predicted biogeochemical dynamics in some embayments in Puget Sound.

Figure I1 shows SOD model predictions for 2006 and 2008. The range of predicted SOD is very similar between the two years: from 0.2 g $O_2/m^2$/day to 1.4 and 1.3 g $O_2/m^2$/day for 2006 and 2008, respectively. The peak difference between the existing and reference scenarios in both years is about 0.4 g $O_2/m^2$/day.

Pelletier et al. (2017a) compared predicted annual (2006) SOD means with observed means available at various locations in Puget Sound, albeit collected at different times and durations. Upon conducting a similar comparison, including predictions for 2006, 2008, and 2014 and a new observational data set (Merritt, 2017), we obtained analogous statistics. Figure I2 shows this comparison of mean-predicted and observed SOD spatially, though not temporally, matching observation means with prediction means. The large difference (about 51%), which is not entirely unexpected, may be due to a combination of the following factors: model bias, incongruent temporal or spatial scales, or potential biases associated with measuring sediment fluxes (Engel and Macko, 1993).

Pamatmat and Banse (1969) conducted SOD measurements and reported them in units of ml $O_2/m^2$/ hr. Although the same type of comparison as outlined above is not possible with this data set given lack of information of the exact coordinates of measurements, the maximum rate they observed is roughly 1.2 g/m$^2$/d in South Sound, and the minimum is 0.2 g/m$^2$/d in the central main basin. The SOD rates that they observed fall within the ranges modeled.

**A** **B** **C**

**2006**

**2008**

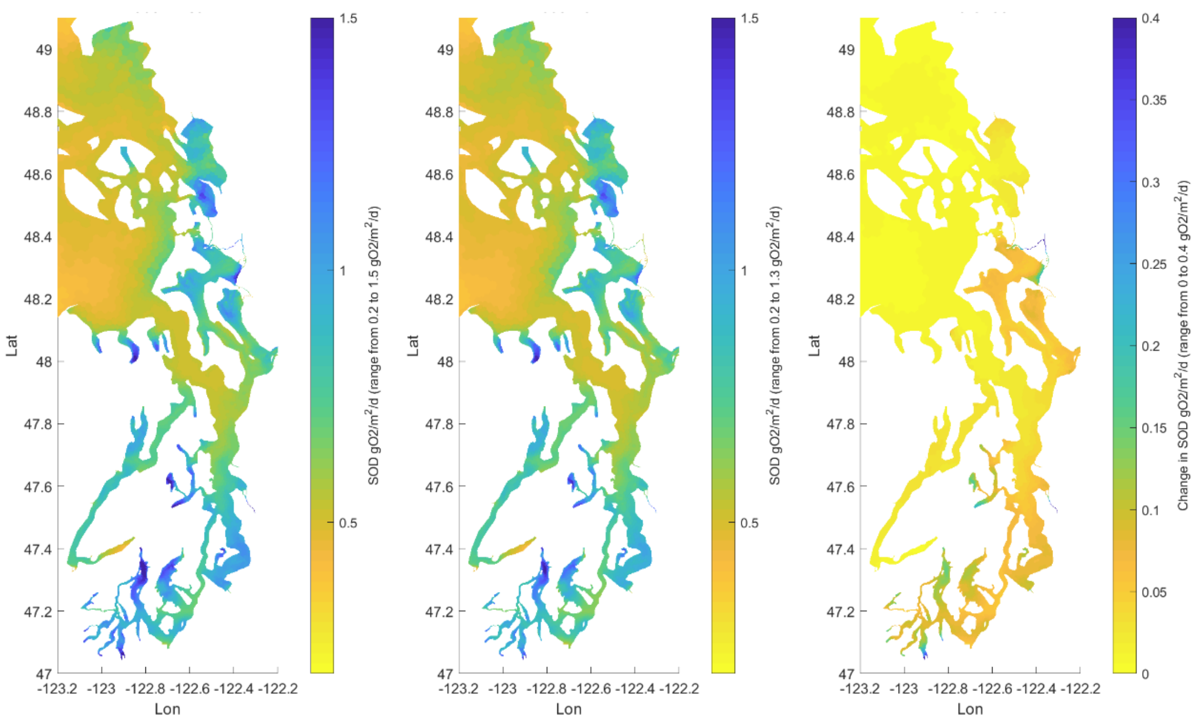


Figure I1. Maps of sediment oxygen demand (g O2/m2/day) for 2006 and 2008 for the existing scenario (A), reference scenario (B), and the difference (C) between them.

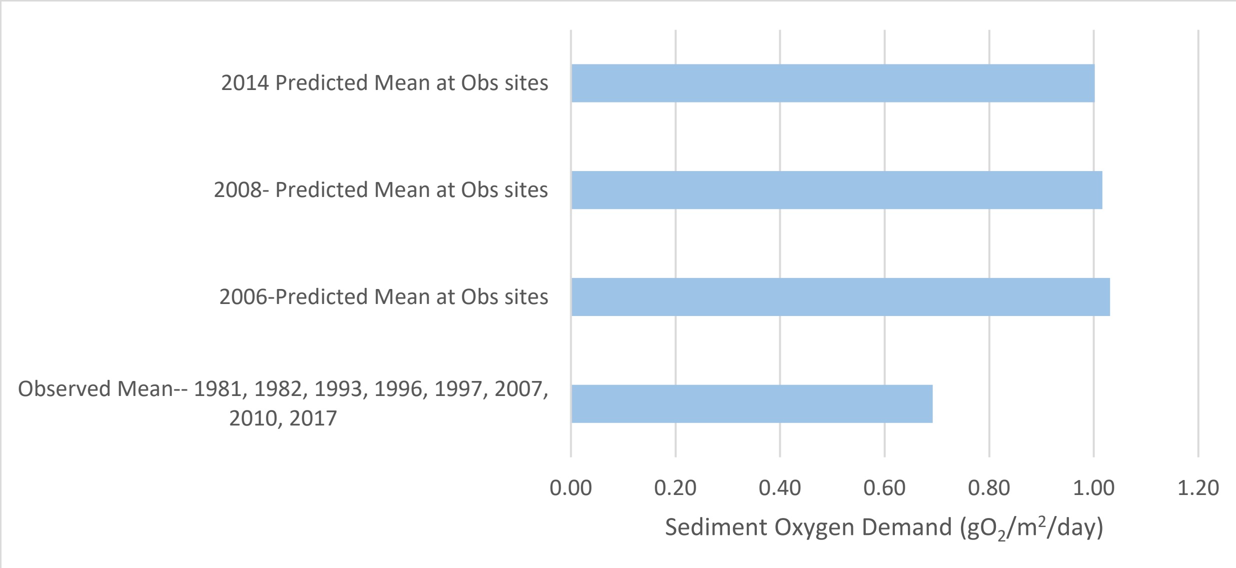


Figure I2. Comparison of predicted and observed SOD at multiple locations but different times.

We conducted a limited comparison of model predictions with a subset of the Merritt (2017) observations. This data set consists of sediment flux measurements, conducted in June of 2017, at locations within Bellingham Bay, with observational clusters in which samples collected were close enough to each other that, in some instances, they fall within the same model grid cell. While the Merritt observational data demonstrate high SOD spatial variability, the data are not temporally rich. To investigate the spatial variability in the observations as it relates to predicted model grid means, three grid cells with more than one observation were selected for a closer comparison with model output. Two of the grid cells are shoreline boundary cells and one of the grid cells is closer to the inner bay, as shown in Figure I3. Table I1 contains the summary statistics for those cells. Note the large coefficients of variation in the observational data set.

Table I2 contains the results of a nonparametric analysis conducted to test if the difference in the observational mean for the predicted grid cells was statistically significantly different from predicted means. We composited the predicted data for June for each of the three model years available, and resampled with replacement the hourly model output, computing randomly selected 15-hour means (to correspond with each measurement which was incubated up to 15 hours), and computed the Bootstrap-t confidence intervals at the 2.5 and 97.5 percentiles. We compared that interval with the corresponding confidence interval for observational means. Predicted means for both boundary grid cells (6562 and 6666) were slightly statistically significantly higher than the observational mean for June 2017. On the other hand, the predicted means for the grid cell away from the shoreline (6665) was not statistically different than the than the observational mean.

Meritt (2017) found that the ratio of DO to DIC fluxes was consistently less than one, implying that anaerobic organic carbon remineralization may be a dominant process in this area, leading to the formation of sulfides. This possibility merits investigation, as Bellingham Bay is cataloged as having adversely affected benthic communities (Weakland, 2018). A potential explanation for the difference between oxygen uptake and aerobic organic matter remineralization is higher organic sedimentation and burial rates. The model currently uses uniform settling rates.

Resuspension of particulates to the water column is another factor that is important, but not separately resolved in the model. Observational data to modulate these rates throughout the model domain is currently not available, but may be needed to refine predictions at areas such as Bellingham Bay.

Meritt (2017) also found that although mean water column respiration was greater than oxygen uptake in the sediments, the difference was not statistically significant. The proportion of organic nitrogen that undergoes denitrification was not measured, but the authors noted that DIN to DIC ratios measured were lower than the Redfield ratio. Data from another site close to point sources — station 53 (Figure I1 shows arrow pointing to approximate location) — suggests that anoxic processes were dominant at that location during the times of the observations. It is necessary to conduct further analyses to determine whether model results can help explain observations and vice-versa.

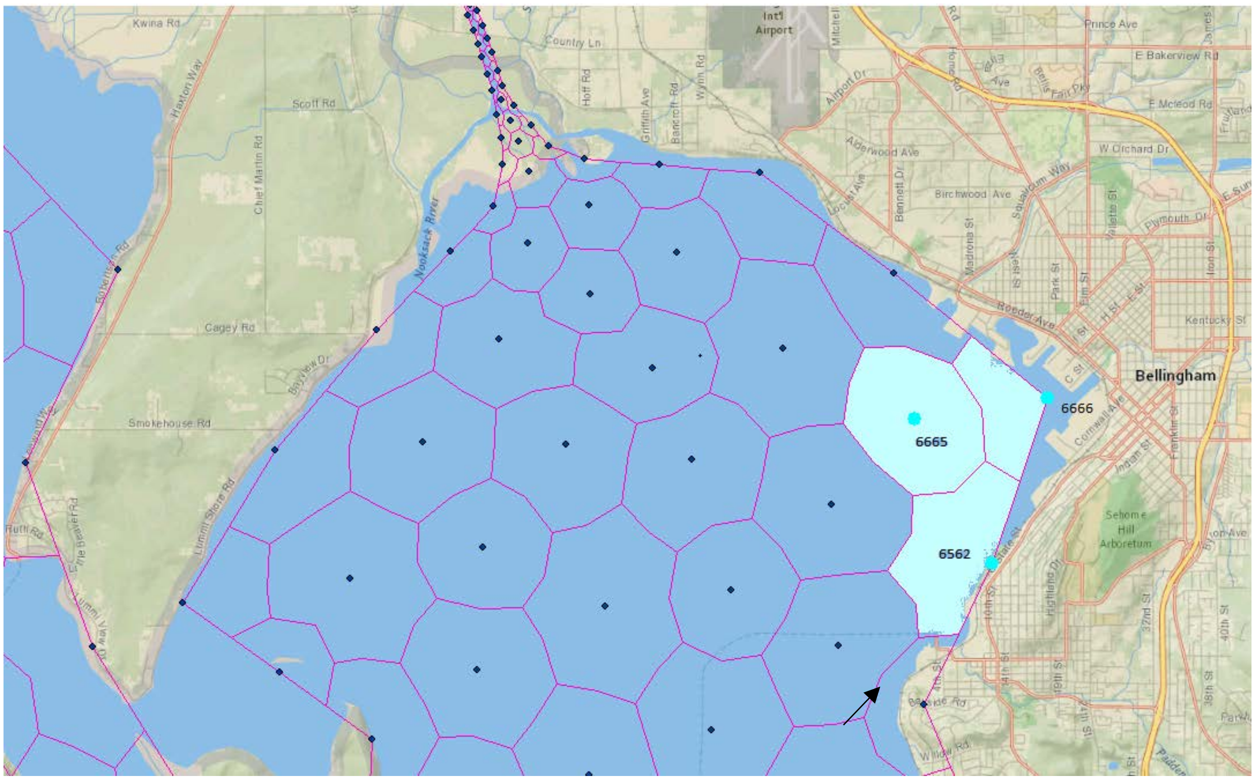


Figure I3. Map of Bellingham Bay showing model grid cells (light blue) that were compared to Merritt (2017) observations.

Table I1. Comparison of observed and predicted SOD at model grid cells in Bellingham Bay.

| **Model grid cell identifiers** | **6562** | **6666** | **6665** |
|---|---|---|---|
| | | | |
| **June 2017 Observations** | | | |
| Mean | 0.71 | 0.88 | 1.25 |
| Standard deviation | 0.21 | 0.07 | 0.28 |
| Coefficient of variation | 29.97% | 8.28% | 22.02% |
| | | | |
| **June-2006 Predictions** | | | |
| Mean | 1.01 | 1.15 | 1.21 |
| Standard deviation | 0.04 | 0.05 | 0.05 |
| Percent difference of means compared to observations | 42.62% | 31.29% | -3.66% |
| **June-2008 Predictions** | | | |
| Mean | 0.94 | 1.06 | 1.12 |
| Standard deviation | 0.05 | 0.07 | 0.07 |
| Percent difference of means compared to observations | 32.84% | 21.41% | -10.74% |
| **June-2014 Predictions** | | | |
| Mean | 0.88 | 1.05 | 1.08 |
| Standard deviation | 0.05 | 0.07 | 0.07 |
| Percent difference of means compared to observations | 24.19% | 19.62% | -13.66% |

Table I2. Results of nonparametric analysis comparing observed and predicted SOD means at three Bellingham Bay Grid Cells.

| **Statistic** | **Bellingham Bay Grid Cells** | | |
|---|---|---|---|
| | **6562** | **6665** | **6666** |
| Observed Mean – June 2017 | 0.71 | 1.25 | 0.88 |
| Standard error of observed mean | 0.07 | 0.12 | 0.04 |
| Confidence interval of observations (2.5%, 97.5%) | (0.52, 0.89) | (0.97, 1.62) | (0.83, 0.93) |
| Predicted Mean – Composite of June 2006, 2008, and 2014 | 0.94 | 1.14 | 1.09 |
| Standard error of predicted mean | 0.0015 | 0.0018 | 0.0017 |
| Confidence interval of predictions (2.5%, 97.5%) | (0.94, 0.95) | (1.13, 1.14) | (1.09, 1.09) |

## References


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