Anthropogenic Dissolved Oxygen Impacts in Budd Inlet: Comparing Influences from a Lake or Estuary

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Abstract

Portions of Budd Inlet do not meet Washington State water quality standards and are on the federal Clean Water Act Section 303(d) list for dissolved oxygen (DO). The *Budd Inlet, Capitol Lake, and Deschutes River Total Maximum Daily Load Study* involved (1) data collection to characterize the sources and processes relevant to the impairments and (2) development of a calibrated computer model to predict circulation and water quality characteristics. Major processes included in the model were DO depletions due to decay of algal blooms (previously mediated by anthropogenic nutrient loading) and steady-state oxygen depletion in the sediment.

DO concentrations under natural conditions were predicted using the calibrated computer model. Natural conditions means no human sources of nutrients and no Capitol Lake dam. Finally, predicted DO concentrations under existing conditions were compared with natural conditions to assess temporal and spatial violations of the standard.

The combined effects of nonpoint and point sources currently do not meet the pollutant loading capacity of Budd Inlet and Capitol Lake for nutrients in southern Budd Inlet. Pollutant load reductions are required to meet State water quality standards for DO.

The effects of Capitol Lake dam, even with only natural nutrient loads, also do not meet DO standards in Budd Inlet. Areas not meeting standards extend from southern to central Budd Inlet.

There is a critical area in East Bay of Budd inlet where the magnitude of the DO violation is the largest. At this location Capitol Lake dam causes a DO depletion of about 2 mg/l compared with natural conditions. The rest of the depletion (approximately 1 mg/L) is caused by the combined effects of anthropogenic nutrient loads from the open boundary (external sources) and local point and nonpoint sources.

BUDD INLET MODEL

The Budd Inlet model is a 3-dimensional hydrodynamic and water quality model based on Environmental Resources Management's (ERM's) GEMSS framework (Roberts et al., 2012). A plan view of the model grid is shown in Figure 1. In this report we present additional information on anthropogenic depletion of DO including (1) redefining natural conditions to include natural open boundary water quality conditions and (2) defining sediment fluxes under natural conditions.

Natural Condition

1. There is no dam at the Capitol Lake outlet.
2. All wastewater discharges are absent.
3. All tributaries are at natural conditions for nutrients.
4. Open boundary water quality is at natural conditions [scalars obtained from South Puget Sound (SPS) water quality model (Ahmed et al., 2014), Figure 2].
5. Sediment fluxes are at natural conditions (obtained from particulate N flux to bottom) (Figure 3).

Existing Conditions

1. Lake_In option: All point and nonpoint sources are at existing conditions, **with** dam at Capitol Lake outlet.
2. Lake_Out option: All point and nonpoint sources are at existing conditions, with **no** dam at Capitol Lake outlet.
3. Anthropogenic load at the open boundary is split between external anthropogenic load and internal anthropogenic load refluxed back at the open boundary [reflux fraction obtained from South and Central Puget Sound model (Ahmed et al., 2014) by comparing water quality of landward flow at open boundary under natural condition and natural condition plus LOTT Wastewater Treatment Plant (WWTP) discharge].

Comparing influences with and without Capitol Lake dam

1. Model results show that DO concentrations in Budd Inlet at various stations (Figure 4) are higher without Capitol Lake dam in place. Lower DO is predicted at these locations when Capitol Lake is retained as a lake. Both the magnitude and extent of DO standard violations are higher with the lake in place compared with if the lake is converted into an estuary (Figure 5). The dam alone causes a DO depletion of about 2 mg/L (Figure 6).

2. Decreased DO in the critical areas of East Bay in Budd Inlet is due to increased residence time due to discharge at Capitol Lake dam which tends to "trap" the water in East Bay. The flushing time (e-folding time) for the bottom layer of the critical cell (Figure 7) in East Bay is approximately 8 days without the dam and about 10 days with the dam in place (Figure 8). This results in poor flushing of East Bay under the Lake_In scenario.

3. With the dam in place, the lake discharges more carbon (and less nitrogen) into Budd Inlet compared with if the dam were removed. There is almost 5 times more carbon and 3 times less nitrogen under the Lake scenario compared with the Estuary scenario (Figure 9). The increased carbon would deplete DO in Budd Inlet through increased biochemical oxygen demand.

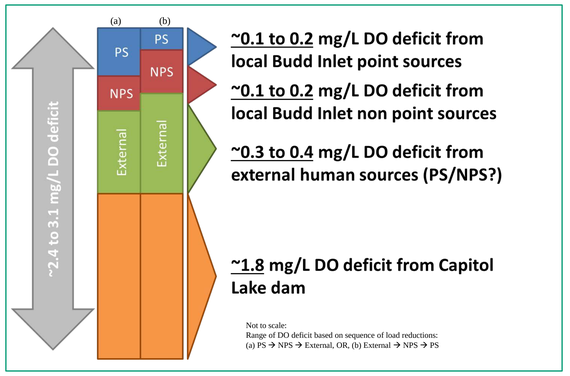


Figure 6. Budd Inlet model results for critical cell in East Bay – DO deficits from existing sources.

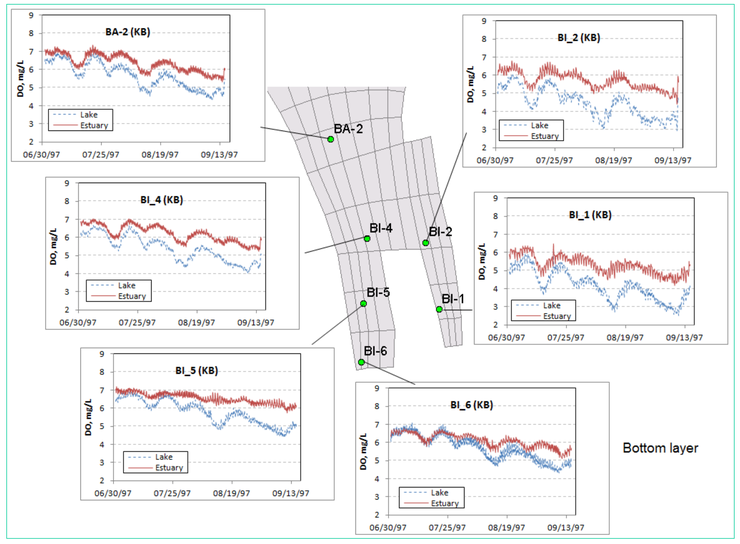


Figure 4. Model predicted dissolved oxygen in bottom layers at specific locations in Budd Inlet under Lake and Estuary scenarios.

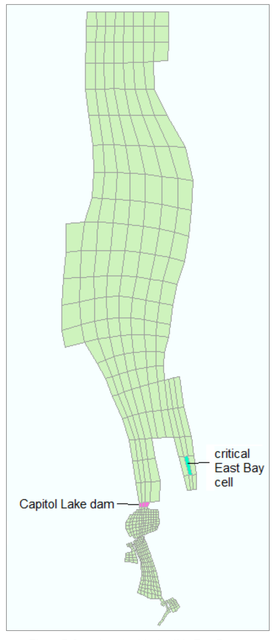


Figure 7. Location of critical cell in East Bay.

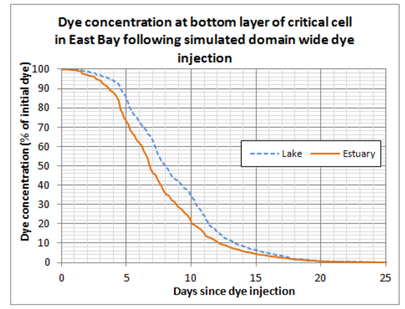


Figure 8. Residence time at the critical East Bay grid cell.

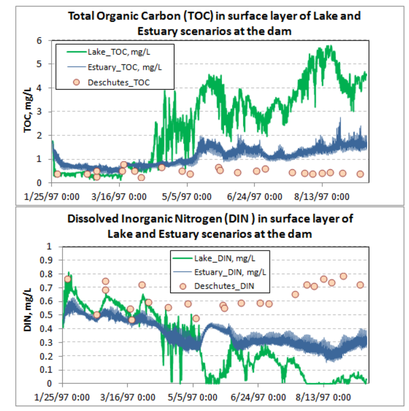


Figure 9. Total carbon and nutrients released at the Capitol Lake dam location under Estuary and Lake scenarios.

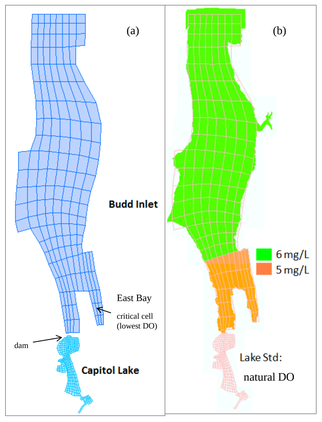
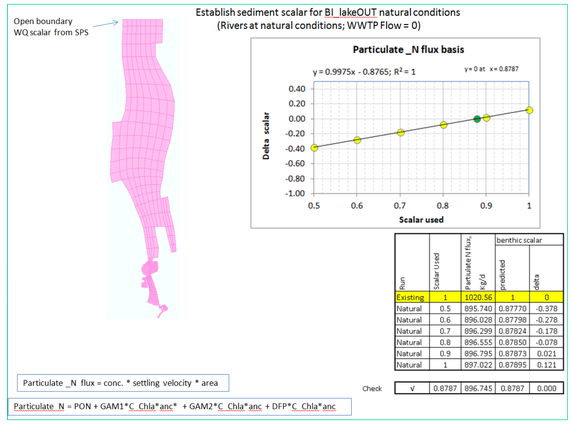


Figure 1. Model grid (a) and dissolved oxygen standards (b).

Figure 2. South and Central Puget Sound Model.



Run	Scalar Used	Particulate N flux, kg/d	benthic scalar predicted	Delta
Existing	1	1020.56	1	0
Natural	0.5	895.740	0.87770	-0.378
Natural	0.6	896.028	0.87798	-0.278
Natural	0.7	896.299	0.87824	-0.178
Natural	0.8	896.555	0.87850	-0.078
Natural	0.9	896.795	0.87873	0.021
Natural	1	897.022	0.87895	0.121
Check	√	0.8787	896.745	0.8787	0.000

Figure 3. Estimating sediment flux scalar under natural conditions.

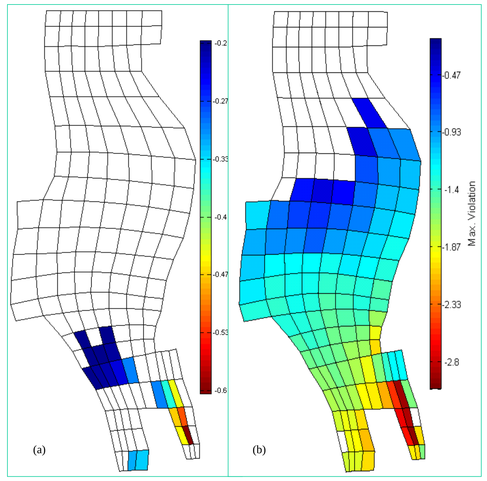


Figure 5. Dissolved oxygen standard violations under (a) Estuary and (b) Lake scenarios.

CONCLUSIONS

Anthropogenic DO depletion in Budd Inlet includes the effects of point and nonpoint sources, increased organic carbon load from Capitol Lake with the dam in place, and increased stagnation in East Bay caused by flow from Capitol Lake with the dam in place. Removing the dam would increase DO in critical areas of Budd Inlet, likely through improving flushing of East Bay and reducing organic load to Budd Inlet.

References

1. Roberts, M., A. Ahmed, G. Pelletier, and D. Osterberg. 2012. Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Technical Report: Water Quality Study Findings. Washington State Department of Ecology. Publication No. 12-03-008. https://fortress.wa.gov/ecy/publications/summarypages/1203008.html.

2. Ahmed, A.,G. Pelletier, and M. Roberts. 2014. South Puget Sound Dissolved Oxygen Study: Water Quality Model Calibration and Scenarios. Washington State Department of Ecology. Publication No. 14-03-004. https://fortress.wa.gov/ecy/publications/summarypages/1403004.html.