Capitol Lake and Puget Sound.
An Analysis of the Use and Misuse of the Budd Inlet Model.

David H. Milne PhD
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1. INTRODUCTION.

In September 2015, the Washington Department of Ecology (WDOE) released a report entitled

Deschutes River, Capitol Lake, and Budd Inlet
Total Maximum Daily Load Study
Supplemental Modeling Scenarios.

Publication No. 15-03-002

This "SM Report" analyzes data obtained from a computer model that simulates various hydrographic and chemical/biological processes in Budd Inlet.[1] Its main focus is on Capitol Lake and the dam that separates it from Puget Sound. It presents many modeling scenarios implicating Capitol Lake as the underlying cause of theoretical water quality violations (specifically depleted dissolved oxygen) in adjacent Budd Inlet and discounts or fails to mention several other possible causes.

In brief, the Report appears to be hastily written with many significant and insignificant errors, flaws, and oversights. Significant errors include a misleading miscalculation of "oxygen depletion" in Capitol Lake. Additional likely errors include calculations that appear to understate the amounts of total organic carbon (TOC) in the water in a modeled estuary scenario and overstate the comparable amounts of TOC in a modeled lake scenario. A formatting difficulty occurring throughout the Report is that the scales of graphical Figures are numbered in ways that defy easy interpretation. *Most serious of all, the authors appear to assume from the outset that their premise – "Capitol Lake damages Budd Inlet" – is correct, and thus overlook a plethora of data in their own Report that strongly suggests the opposite.* In the following, I discuss and analyze the SM Report.

I have written this paper for two groups of readers; the lay public and for persons with scientific backgrounds who may wish to check my reasoning and calculations. On behalf of the former, I have used non-technical language wherever possible. This includes using short-cut references in my text instead of the conventional scientific format of documentation, for example saying "SM Report" instead of "Roberts, Pelletier and Ahmed, 2015" whenever I mention that Report as a source. (Likewise mentioning "TMDL Report" instead of "Roberts, Ahmed, Pelletier and Osterberg, 2012" whenever I refer readers to that earlier document.) The References Section gives the full documentation,

[1] This "Budd Inlet Model" is described in WDOE's report of June 2012. See "TMDL Report 2012" in the REFERENCES section.

both in my abbreviated forms and in scientific format. In the following I refer to my own (the present) document as an "Analysis" to distinguish it from WDOE publications, referred to as "Reports."

On behalf of scientific readers, I have documented *all* of my own calculations in detail enough to enable them to trace my logic, and have used the right technical language where that is essential.

I regret that my time for analyzing the SM Report was critically limited. It seemed likely, while I was doing it, that I would have to leave this project unfinished. To that end I wrote this paper by sections, each of which could stand alone if my departure was required. My time for research and writing did indeed run out; the following sections are the result.

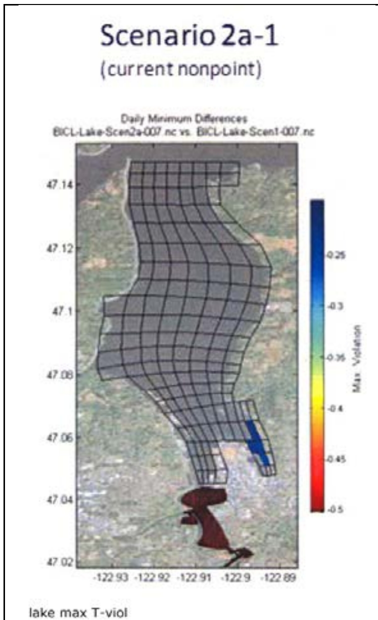

Figure 1-1. WDOE's depiction of the maximum theoretical impact of Capitol Lake and other non-point sources on dissolved oxygen conditions in Budd Inlet (TMDL Report, Figure 90a, p. 206). Fine print in the original at the top of chart reads "Daily Minimum (sic) Differences ECL-Lake-Scen2a-007 nc vs. BCL-Lake-Scen1-007 nc"

I believe that the origin of the SM Report is traceable back to the image shown here in Figure 1-1. This image is part of a four-part depiction of simulated conditions in Budd Inlet, with this particular image showing the maximum theoretical oxygen depletion caused by "non-point sources," mainly water exiting Capitol Lake and all other (tiny) streams around the shores, excluding any effects by the LOTT (Wastewater Treatment Plant) outfall at the end of the Port peninsula.[2] The grey areas in Budd Inlet are those where not even the tiniest of theoretical oxygen depletion violations could be detected by the computer. (That is, almost the whole Inlet.) The few colored patches in East Bay show theoretical violations in a peculiar format. That is, each colored square shows the *maximum* theoretical oxygen depletion that occurred there at some depth (not specified) on some date (not specified) during the entire simulation period January 25 – September 15, 1997. The size of the maximum theoretical violation can be read from the colored scale to the right. This Figure, with a few others like it, was presented as all the evidence that anyone needs to see to conclude that Capitol Lake degrades Budd Inlet. My involvement with this topic began with my questions about this Figure in 2013.

In encounters with the WDOE staff (described below), I pointed out that these "violations" were so localized and microscopic as to be almost undetectable by a dissolved oxygen (DO) meter in real life, and that if this is really the maximum negative

[2] The caption of the 4-part figure in The TMDL Report is "Figure 90. Predicted maximum violation of the DO water quality standard under the lake scenarios. The layer with the maximum violation is plotted for each grid cell." (Alternative "estuary scenarios" in which Capitol Lake is replaced by a 'natural' estuary are presented in a separate TMDL Report Figure.)

effect of Capitol Lake on Budd Inlet, then in reality there is no problem whatsoever. That seems to have set off an alarmed scramble (described below) to "prove" that "oops, we've fixed the model and *now* it shows that the Capitol Lake effect is huge." The SM Report that I review here is the latest result of that "alarmed scramble."

1a. The Budd Inlet Computer Model.

For persons who are not familiar with the Budd Inlet computer model, a few words of description are in order. The model was crafted and first used in 1997 by consultants from the Aura-Nova (Seattle) consulting firm (and other firms and entities) for predicting effects on Budd Inlet of proposed changes in Olympia's LOTT wastewater treatment plant. It subdivides Budd Inlet into about 160 "cells" (or "grid squares") that cover the entire surface of the Inlet (seen in Figure 1-1 above).[3] Beneath each grid square, the water is subdivided into a stack of about 19 "grid cubes" that include all of the water from surface to bottom. The total number of cubes that divide up the three-dimensional body of water that is Budd Inlet is therefore about 160 x 19 = 3040. The computer begins on simulated "January 25, 1997." It starts with a vast amount of observed and interpolated data from (or starting from) that date – water salinity, temperature, dissolved oxygen levels, and other water properties in each one of the 3040 "cubes," the 1997 tide table, 1997 weather and stream runoff data, and more. Using the starting data and built-in calculation routines that mimic the transfers of water between adjacent cubes and processes that create and/or use up dissolved oxygen (and change its chemistry in other ways), the computer then calculates the changes in each cube that take place as time goes by – *every six minutes for every depth at every location* – from January 25 to September 15 (TMDL Report, p. 187).[4] A single "run" of the model from start to finish takes 10 full [24-hour?] days to complete even at the lightning speed of the computer (SPSDOS Report 2013, p. 38).

If even one of the six minute intervals at even one depth under any of the grid squares is found by the computer to have less dissolved oxygen in it than the legal regulatory water quality standard[5], the whole grid square is colored according to the size of its simulated low oxygen condition and shows up at the end of the simulation flagged, as in the colored East Bay squares in Figure 1-1. The smallest low oxygen condition triggering a "violation" color is a DO level 0.2 mg/L below the standard – the blue top end of the scale in Figure 1-1. As can be seen, the simulation that produced that Figure subjected Budd Inlet to a gargantuan dragnet search of staggering size – colloquially, a search with a fine-tooth comb -- and, even so, failed to find any theoretical violations even this small over almost all of the Inlet.

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[3] The number of grid squares is not always the same in WDOE reports. For example, two side-by-side grids on p. 32 of the SM Report (reproduced as Figure 2-7 below) show different numbers, 160 and 168. I use 160 throughout this report.

[4] In scientific parlance, six minutes is the "iteration interval" of the model.

[5] The regulatory water quality standard is complex. It is described in detail in Section 2.

1b. Data Sources.

The consulting firm that devised the Budd Inlet Model, in partnership with others, also conducted a year-long field study of Budd Inlet. Beginning in September 1996 and finishing in September 1997, measurements were made regularly at some stations and less frequently at others on some 34 different occasions throughout the study year.[6] The scientists involved measured water quality properties at depths ranging from the surface to the bottom at the locations shown in Figure 1-2. To date, this "Budd Inlet Scientific Study" (= BISS in the following) is the most detailed and reliable study of Budd Inlet ever made.

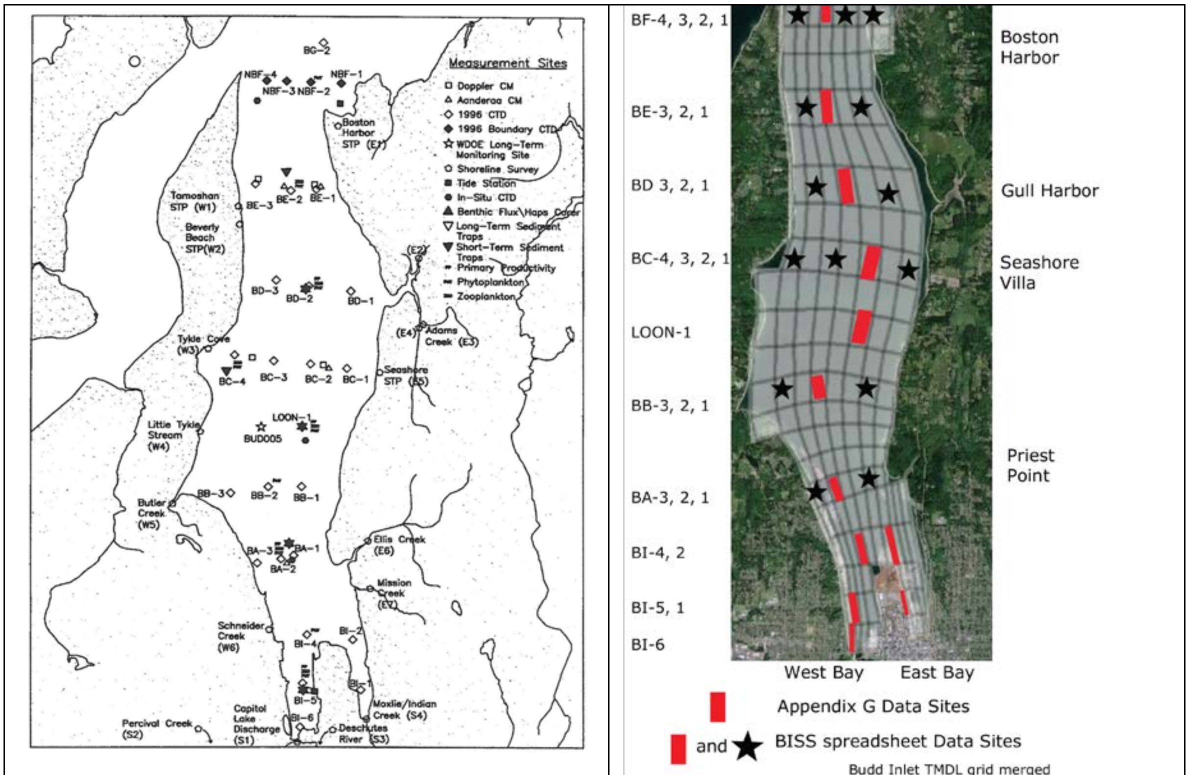

Figure 1-2. (Left) All BISS sample sites in Budd Inlet with a key to observations made at each site. Source: BISS Vol. 1 p. 59, 1998. Figure 1-2. (Right) Sites for which 1996-1997 data are available in Budd Inlet, referred to in this Report. Red bars; data available in TMDL Appendix G. Red bars and stars; data available in the BISS spreadsheet. The BISS spreadsheet also has data for a station BG-2 outside the mouth of Budd Inlet (not shown here).

Some of the data from this study are stored in a gigantic Excel spreadsheet file, which LOTT personnel graciously made available to me. This awesome compilation consists of some 29,000 rows of data spanning the study period, arranged in 14 columns. A sample is shown in Table 1-1. The spreadsheet shows these data at every depth from the surface to the bottom (whose actual depth varies from date to date due to tidal change) in increments of 0.5 meters.

[6] Most of the "occasions" were separate dates, however several sets of measurements were made during the same day on a few dates.

The Budd Inlet computer model used by the WDOE staff was updated and calibrated by comparing its predictions with the values actually observed by the BISS scientists. These comparisons, made after the calibrated model was judged to be as accurate as it could be,

A	B	C	D	E	F	G	H	I	J	K	L	M	N
I	2	BI-1	1/22/97	17:53	7.5	3.9	-3.9	8.12	27.38	21.2789	7.14	1.10082	0.001896
R		BI-1	2/11/97	7:25	7.5	3.0	-3.0	7.93	26.68	20.7563	7.59	3.51059	0.0799
I	3	BI-1	5/29/97	22:08	7.5	3.5	-3.5	11.89	27.34	20.6641	8.00	-999	0.001595
I	4	BI-1	8/21/97	5:29	7.5	3.9	-3.9	15.54	28.31	20.7081	5.02	-999	0.2617
R		BI-1	9/24/97	13:26	7.5	3.5	-3.5	14.73	28.48	21.0101	2.85	9.40895	33.33

Table 1-1. Example of BISS spreadsheet data. Column labels are A, Cruise type; B, Sweep number; C Site ID; D Date; E Time of Day; F Depth below surface (m); G Depth relative to MLLW; H (see Notes); I Water Temperature ºC; J Water Salinity ppt; K Water Density (σ_T); L Dissolved Oxygen Concentration (mg/L); M Chlorophyll Concentration υg/L); N Light level. This example shows bottom water at station BI-1 (head of East Bay, includes the colored squares of Figure I-1) on various dates (Jan. 22 – Sep. 24, 1997), depth 7.5 m below the surface, water temperatures ranging from 8+ to 15+ ºC, salinities ranging from 26+ to 28+ parts per thousand, and DO's ranging from 8.00 to (critically low) 2.85 mg/L over these dates. Some data are rounded to two decimal places; in the spreadsheet they have more. Data under shaded headings are also contained in the TMDL Appendix. Notes: The label on Column H says "Elev". I'm not sure what it refers to. I did not use data from this Column (nor from A, B, and N). "-999" indicates that data were lost or not taken on some occasions.

are shown in a WDOE Report that accompanies the 2012 TMDL Report – namely, the "TMDL Appendix." Here the data are mostly reported in the form of Figures comparing the computer's calculations (as a graph) with observed data (as points). The actual numerical values must be calculated by measurement of the graph scales and interpolation. Table 1-1 shows which data are presented in both the Appendix and in the Spreadsheet. The Appendix also includes graphs for data that are not in the BISS spreadsheet in my possession.

The Spreadsheet and the TMDL Appendix were my major sources of dissolved oxygen data. I found that these two sources are identical in most cases, but also that each has data not shown by the other (see Section 2).

These sources are referenced here as "TMDL Appendix" and "BISS Report 1998."

1c. Encounters with WDOE.

I was invited to examine the claim that Capitol Lake degrades water quality in Budd Inlet in Autumn 2012 by the members of the Capitol Lake Improvement and Protection Association (CLIPA). At that time I knew that there was discussion of the possible removal of the Lake and conversion of its basin back to the estuarine condition that prevailed before the dam at 5th Avenue was built, but this had been remote from my daily concerns and I had no opinion one way or the other on that proposition. I began by obtaining and reading copies of the TMDL Report and TMDL Appendices, and attending monthly meetings of WDOE's "TMDL Advisory Group," a group of professionals, agency representatives, and members of various organizations that met monthly to advise WDOE on restoration of the Deschutes River. This group's agenda included the Lake/Estuary question.

I quickly realized (from Figure 1-1 from the TMDL Report and others like it – Figure 1-3 below, for example) that the computer modeling staff were unfamiliar with aquatic ecology and were missing important interpretations of the model's outputs. It was also clear that no mention was made of Capitol Lake's removal of nitrogen nutrients from the Deschutes River water – an immense benefit to water quality in Puget Sound. These and other oversights were driving the impression that the Lake degrades Budd Inlet.

In early 2014, I requested an opportunity to share my views with the TMDL Advisory Group as a speaker at one of the meetings. The WDOE staff members overseeing the TMDL effort requested a preliminary private briefing to familiarize themselves with what I would say. A colleague and I met with two staffers in March 2014.

Following that briefing, TMDL meetings for the next three months were cancelled. When they finally resumed, the topic was a TMDL effort at Chesapeake Bay featuring a speaker working there.

During the interim "waiting period," I compiled a written report of my findings (Milne, 2014). In it I described and analyzed many shortcomings of the TMDL Report's chapter on Capitol Lake and presented it to the CLIPA group that I was advising. The report was posted on the CLIPA website, distributed in printed form to various interested parties, and made available to the WDOE modeling staff members.

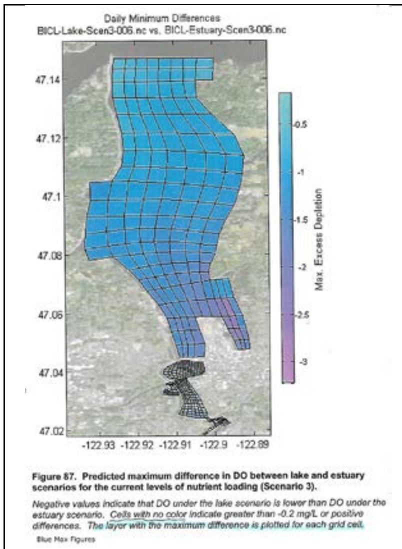

Figure 1-3. Budd Inlet purportedly with less dissolved oxygen everywhere "caused" by the Lake, compared with DO levels if an estuary were present. Source: Figure 87, TMDL Report. [7]

During the interim "waiting period," it was announced by the WDOE staff that a "poster" describing an "improvement" in the Budd Inlet Model had been released (Poster 2014 in References). The modelers had changed the way in which the simulated sediment exchange with the water takes place, and also presented a graph that showed, for the first time, the Lake water removing nitrogen nutrients from Deschutes River water. (This is discussed in detail in Section 3.) The effect of this change was to make Budd Inlet appear to be far more degraded by Capitol Lake than is shown in Figure 1-1 and elsewhere in the TMDL Report.

I met with the WDOE staff on two other significant occasions. The first was a dual presentation by the modelers and by me to the Alliance for a Healthy South Sound on July 17, 2014 (AHSS, 2014). At that time I gave a Power Point presentation correcting

[7] My detailed response to the WDOE modelers regarding this Figure is contained in my Report (Milne, 2014) and also in Power Point slides presented to them on July 17, 2014. The Figure actually shows a flush of surface water oxygen production by Inlet phytoplankton caused by the ongoing flood of nutrients from the Deschutes River – while overlooking the near-inevitable detrimental consequence of that, namely DO depletion at the bottom.

dubious interpretations of Figures in the TMDL Report and suggested alternative hypotheses addressing the conspicuous late-summer low DO levels in East Bay. Two members of the modeling staff gave a complementary presentation in which they advanced an important hypothesis explaining how Capitol Lake might degrade Budd Inlet in spite of the fact that the Lake removes nutrient nitrogen from the Deschutes River. This was a cordial, informative exchange that advanced the thinking of all of us on new ways to explore the Lake/Inlet interaction. I left a copy of my presentation with the modelers at this time (Power Point "OK," 2014.)

After the OK presentation, I left a telephone message with one of the modelers suggesting we all get together over coffee and continue our conversation about the model. This turned into something far different. The TMDL overseers worried that "Estuary advocates" would demand to know why they hadn't been included and scheduled a meeting of people said to be knowledgeable about simulation modeling and aquatic ecology. The meeting, which included mostly people with little such knowledge, was held on November 3, 2014. Again the modelers and I gave presentations. Mine included a printed list of ways in which I thought the model could be improved for greater accuracy (included at the end of this entire Analysis as an Appendix), which with a copy of the Power Point presentation (Power Point OK2, 2014), I left with the modelers. This meeting was somewhat confrontational. The "Estuary advocates" brought an expert on freshwater ecology, Dr. Jonathan Frodge, who had critiqued my earlier report (Frodge, 2014). To their chagrin, he and I had an agreeable and informative discussion of aquatic ecology, all overshadowed by our growing realizations that this meeting was political, not scientific.

Following this meeting, I turned my attention to addressing the public's widespread negative perception of Capitol Lake. To this end I wrote a report that presents the Lake as a truly remarkable positive feature of Washington's ecological landscape (Milne, 2015). Whether or not WDOE has a copy I don't know; it is available on the CLIPA website.

As a result of our encounters, the modelers appear to have adopted some of my suggestions. The new SM Report includes a discussion of how the Budd Inlet model has been grafted onto their model of Capitol Lake (SM Figure 6, p. 31), moves away from the earlier preoccupation with the "depth of maximum dissolved oxygen difference" and addresses instead the bottom water in one case (SM Figure 15, p. 38), and gives a nod to statistical confidence limits. None of this is acknowledged by WDOE; the SM Report's References section makes no mention of any of my written or presented contributions.

Two special features of the modelers' effort and interpretations are mentioned here. One is their apparent lack of appreciation of certain vast differences between the Capitol Lake and Budd Inlet systems. The other is their apparent oversight of an important natural estuarine phenomenon, namely the seasonal formation of "null zones."

1d. The Special Case of Capitol Lake.

To include Capitol Lake in their simulations, the modelers devised a clone of the existing Budd Inlet Model, using the same principles of calculation, and fitted it to Capitol Lake. If surface area alone were a main criterion, the tiny Lake would merit about 16 grid squares (using the same scale as in Budd Inlet). Surprisingly, the modelers divided it into 280 squares, nearly twice the number used for all of Budd Inlet. No mention of the reason for this is made in the TMDL Report and its Appendix, where sections are devoted to changes made in the Budd Inlet model to extend it to Capitol Lake (TMDL Report, pages 187 – 197; TMDL Appendix H). Likewise no mention is made of the number of depths needed in the Capitol Lake part of the extended model. The TMDL Appendix states that the shallow water in the Lake is so homogeneous that one hardly need bother at all about differences between depths – that is, that the water column as a whole under each grid square can be treated as a single "cube." Whether or not the modelers do so is not stated.

The real difficulty with trying to drag Capitol Lake into a simulation devised for Budd Inlet is that the Lake's ecosystem is vastly different from that of Puget Sound. The large plants and other biota of the Lake constitute a vast nutrient-collection- and carbon-storage- system on a scale unlike anything in southernmost Budd Inlet. The carbon compounds formed by plant photosynthesis are stored for days, weeks, months or years in the structures (roots, stems, leaves) of the plants and the organisms that eat them or their decaying byproducts (clams, fish, birds, insects, snails, worms). Many of these organisms have long lifetimes and can store carbon and nutrients in their bodies for a year or more. This huge rich complex ecosystem intervenes between the input of high-nutrient water from the Deschutes River and the output of "lake-treated" water at the dam. Simulation of its effects on the water would require creation of a whole additional ecosystem model tracing the uptake of nutrients, their storage in plant biomass, their transfers to animals via herbivory and detritivore feeding, and processes such as predation, competition, and "leakage" of materials back into the water with consequent continued recycling. There are also significant differences in the species makeup, characteristics, and life cycles of freshwater- and marine- phytoplankton organisms and the small animals that eat them to be considered. The freshwater biotic community is a system that the Budd Inlet model was never constructed to emulate; a once-over-lightly extension created by the modelers cannot possibly cover it accurately.

The modelers' only significant statement on how the Lake's biota were simulated is a single sentence describing a new subroutine added to the Budd Inlet model, namely "Water Quality Additional Model (WQADD) can simulate a combined bottom plant community of macrophytes, epiphytes, and attached algae *as a lumped variable*" [8] (TMDL Report, p. 188). The results – and absence of results – of their attempt to force-fit the Lake ecosystem into a model designed for an estuary system are evident in the pages of the SM Report (see Section 3, this Analysis).

[8] … emphasis added …

1e. The Natural Null Zones of Estuaries.

In addition to what appears to be inadequate appreciation of the special complexities of freshwater ecosystems, the modelers appear to be unaware of one of the most important natural features of estuaries. That feature is the "null zone," a pocket of low dissolved oxygen that develops in late summer at the heads of most estuaries, arising from entirely natural causes. Figure 1-1 above shows an example of a null zone, this one the colored region of exaggerated low DO in East Bay caused by Moxlie Creek. Again and again throughout the SM Report, East Bay's DO null zone can be seen, markedly more oxygen-depleted than any other locale in Budd Inlet. The modelers seem to regard such zones as phenomena caused entirely by human activities. Regardless of interpretation, if interactions between fresh and salt water at the point where they meet were accurately simulated when the model was constructed, the Budd Inlet model would show those zones. As shown in many of the Figures in the following sections, it seems to do so consistently.

An example of the modelers' interpretation of null zones can be seen in WDOE's South Puget Sound Dissolved Oxygen Study Report (SPSDOS 2013). The model used in that Report operates on the same principle as the Budd Inlet model but has been expanded to include all of Puget Sound south of Edmonds. In the Figures generated by that model, the head of Eld Inlet -- an estuary with no dam, no urbanization, and a rural/forested stream drainage basin – obstinately continues to show low DO's below modern water quality standard levels even after the modelers have reduced human O_2-depleting sources by 75% throughout all of Puget Sound (see Figure 51 p. 96, SPSDOS 2013).[9]

In the Eld Inlet case, the modelers attribute the low oxygen phenomenon to "poor circulation." That is mistaken. The "null zone" forms in the small restricted region where the incoming saltwater at the bottom of an estuary collides with the incoming freshwater from the river at the head. Here dissolved organic matter in both incoming streams is chemically and physically converted to colloidal (small) particles by the abrupt change in salinity and other changes in the water chemistry. Where the waters collide, the net horizontal velocity drops to zero and the newly mixed waters rise. In this zone of slower water movement, the newly formed colloids accumulate, aggregate, and sink. Their decay causes a low DO condition at the bottom in this small region at the head of every estuary.

Understanding and recognition of this estuarine phenomenon is not widespread. An excellent detailed description of it is provided by Mann (1982).

I mentioned this phenomenon during the March 2014 meeting with WDOE staff. Tiny Moxlie Creek at the head of East Bay has one of the highest nitrogen nutrient concentrations in its waters to be found anywhere among all South Puget Sound streams

[9] Eld Inlet is the most resistant of all estuaries to simulated efforts to eliminate its null zone by curtailing human activities. The second most obstinate inlet in that regard is the null zone in East Bay in Budd Inlet, still showing DO depletion below the level of water quality standards despite a simulated 50% reduction in human impact.

(SPSDOS 2011, Figure F-2 p. 124). It is at least possible that that small stream (with adjacent high-nitrogen streams, Mission and Ellis Creeks) is responsible for the chronic low DO excursions (that is, the null zone) seen in East Bay and would cause that condition even if there were no human activity at all.

I learned during the March meeting that Moxlie Creek could not (at that time) be simulated separately from the other small creeks around Budd Inlet (at Gull Harbor, Priest Point, Butler Cove and elsewhere). All creeks rimming the Inlet were treated as a single "watershed source." I suggested that it was important to try to isolate Moxlie Creek as a nutrient source to determine whether it was playing a role in the persistent dissolved oxygen depletions seen in East Bay, but have seen no subsequent evidence that the modelers actually did so.

1f. The Analysis That Follows.

In the following, I address errors, mistaken assumptions, and mistaken interpretations presented by the modelers (Roberts, Pelletier and Ahmed) in the SM Report. Central to all of it is the Budd Inlet Model – an impressive (even "remarkable") tool for examining broad scale changes in Budd Inlet. As noted, I believe that the Model falls short in that it has been poorly adapted to mimic the ecology and hydrology of Capitol Lake. I also have reason to believe (and have never been corrected on this by the modelers) that the WDOE staff consider every single one of the model's thousands of projections of dissolved oxygen levels throughout simulated "1997" to be dead-on accurate, close enough to the real levels that prevailed during that year for certainty in every case where the model shows low DO and therefore a theoretical water quality standards violation. All such calculated theoretical violations are invariably reported by them as "real."

Wherever possible throughout the following, I compare the outputs of the computer model and the modelers' interpretations with real, observed data. Where real-life observations show water quality standards violations, that is definitive. Where the computer calculates theoretical water quality standards violations, that is suggestive and instructive – but not evidence of real-world violations.

In addition to this Introduction (Section 1), the rest of this Report is divided into six sections. These are …

2. The Mistaken Assumption of Model Infallibility.
3. The Real and Calculated Role of Organic Carbon.
4. [Blank pages]
5. Miscellaneous Mistaken Assumptions and Presentation Errors.
6. The Mistaken Calculation of Theoretical Water Quality Violations in Capitol Lake.
7. References and Notes.
8. Appendices.