Capitol Lake: Protector of Water Quality in Budd Inlet.

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This report addresses the influence of Capitol Lake on the water quality of Budd Inlet.

> **My findings indicate that the Lake does not have the negative effects on Budd Inlet that are often said to exist and that in fact the Lake almost certainly improves the water quality of that Inlet.**

This report is intended to inform the community discussion of the relative merits of retaining Capitol Lake in its present location or replacing it with a reconstructed estuary. It is not an advocacy paper, nor is it intended to be adversarial to any persons or group now grappling with this important community issue.

I was drawn into this study by the appearance last summer (2013) of letters to the Olympian (some by people I know and respect) conveying views of the Lake's effects on Budd Inlet that I knew to be erroneous. I wondered where their information was coming from, and with help from friends and colleagues tracked it to a primary source. I began a study of that source (the "TMDL Report") in November, 2013.

The TMDL Report presents the results of computer simulations that examined, first, water quality conditions in Budd Inlet with Capitol Lake in place, then second, conditions with the Lake replaced by a reconstructed estuary. Those simulations and their results are described in the sections of this report that follow. The computer model that performed those simulations is an immensely powerful diagnostic tool for analyzing a vast number of water quality conditions in huge bodies of water over the course of a year. Its forte' is to spotlight areas in local waters that are most vulnerable to degradation by changes in human activities and/or certain natural conditions. That is what it is designed to do, and it does that with phenomenal power and accuracy.

The vast store of information that the computer's calculations create can be used for many other kinds of insights about Budd Inlet, including answers to questions I raise in this report. However, if it is not actually programmed by its users to show those other data, it doesn't show them. It was not so programmed for the Lake/Estuary comparisons. Instead, it showed the kinds of data that it is designed to display. *Misinterpretation of those data in this case is, I believe, a key reason why the TMDL Report is mistakenly said to show a negative impact by Capitol Lake on Budd Inlet.*

I hope that the report that follows can be of value to various experts who have read the TMDL Report. To that end, I've provided as much technical detail as I think necessary to show that the data presented there demonstrate no real problems caused by the Lake and indeed that the data demonstrate a positive Lake effect on the Inlet's water quality.

I also hope to inform non-technical readers who are interested in the Lake/Estuary discussion. For their benefit, I include in each section of the report an underlined "take-home" statement; one that says what that section is intended to show. But I have also attempted to express the technical detail in ways that enable all readers to grasp it, whether or not they have read the TMDL Report.

For all readers, I've tried to keep the text straightforward, *as brief as possible*, and "on target." Details that are helpful or interesting but not essential are mentioned in the end-notes to each section. To avoid ponderous language, I use the following abbreviations:

TMDL Report	= "Total Maximum Daily Load Report" by Roberts and other authors (2012), shown in the References section at the end of this report;
L/E Chapter	= "Lake/Estuary Chapter" = the chapter in the TMDL Report (pp. 187 – 212) that presents the Lake/Estuary simulation findings;
BI Model	= the "Budd Inlet Model," the computer model used to perform the Lake/Estuary calculations for Budd Inlet;
S/CPS DO Model	= the "South & Central Puget Sound Dissolved Oxygen Model," a different computer model that uses the same methods of calculation as does the BI Model but which was used to simulate all of Puget Sound from Edmonds to Olympia;
SPS DO Draft	= "South Puget Sound Dissolved Oxygen Study Draft," an unpublished report made available in Draft form in November, 2013, for public comment. The SPS DO Draft describes the S/CPS DO Model simulation work. The Draft is listed under Ahmed and others, 2013, in the References section at the end of this report;
WQ Standards	= "Water Quality" *Standards*; I use this phrase to ensure that the data reported by the BI Model will not be mistaken for Water Quality *Problems* – an entirely different phenomenon.

I bring to this study a detailed "hands-on" knowledge of our local inlets, gained via decades of classroom and field work in marine sciences as an Evergreen State College faculty member. In conducting this research I studied many print resources in addition to the TMDL Report, all of them listed in the References section at the end. Many colleagues and friends in the shellfish industry, at Evergreen, in the "Capitol Lake Improvement and Protection Association," and elsewhere have been helpful with answers to my questions and suggestions for further research. As with all analyses of data, there is always a chance that I am mistaken and that some other interpretation of the same data may be closer to "the truth." For that reason I use the usual tentative language of science; "almost certainly," "probably," "appears to be" and the like where appropriate – not phrases like "is definitely," "causes," "undoubtedly," etc. This is not to be construed as doubt on my part that the interpretations I offer are correct. I believe them to be correct and would not put them in writing with my name on it, if I thought otherwise.

Section 2. The Budd Inlet Model and Its Simulation Results.

For modeling purposes, the surface of Budd Inlet is divided up into 168 grid squares (see Fig. 1)[i]. The water beneath each square is divided up into some 19 layers spanning the depths from surface to bottom. (Some cells in some of these layers may have no water in them during low tides.) During each simulation, the computer starts on January 15 and proceeds to September 15, examining every last cell of this giant 3-d grid, calculating the dissolved oxygen (DO) in each cell and comparing it with a simple pre-assigned water quality standard (for example, 5.0 mg DO/L throughout East and West Bays) or a more complicated standard in some places.[ii] If the calculated DO drops below the standard by

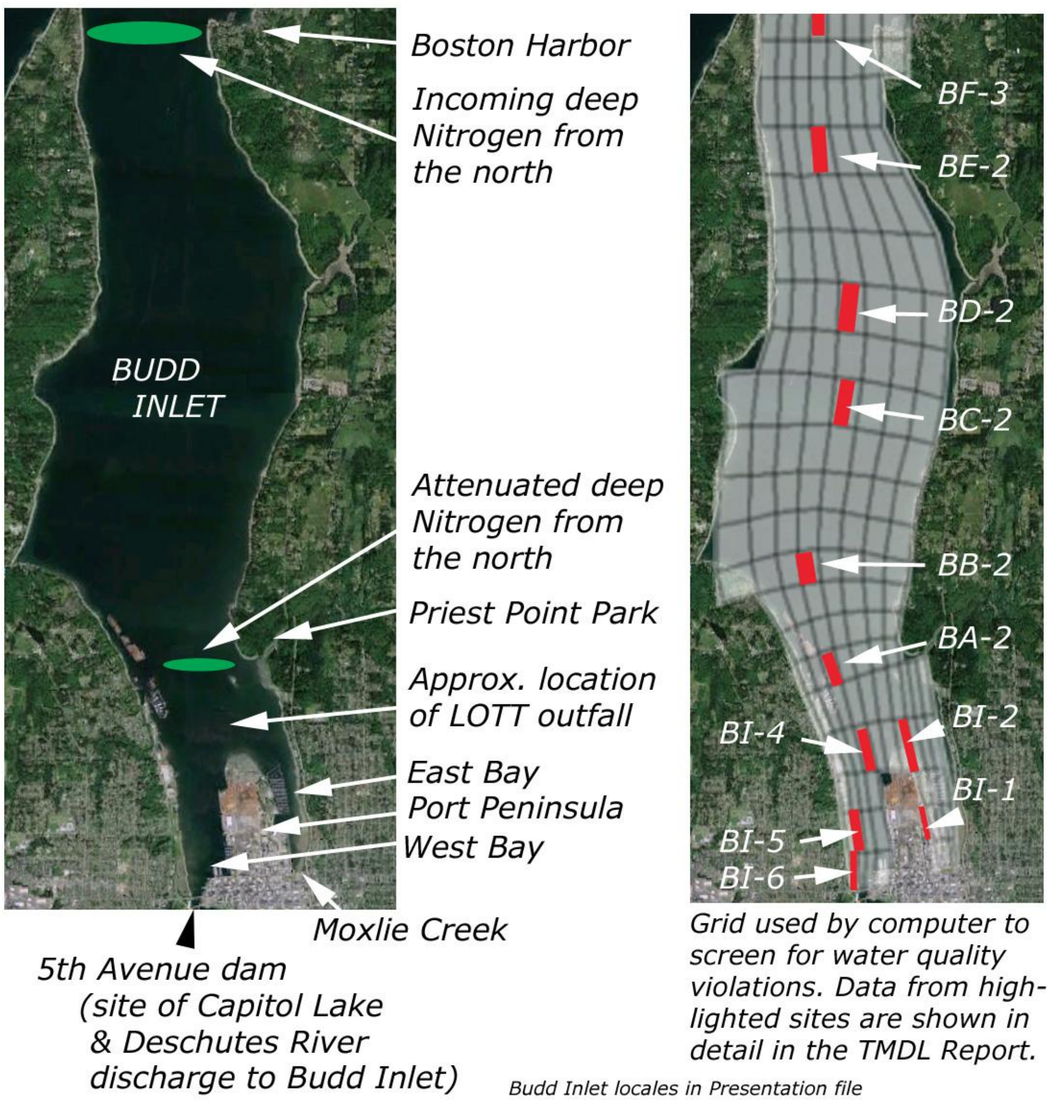


Figure 1. Left. Budd Inlet with sites and phenomena mentioned in this report. Right. Grid used by the BI Model to screen Budd Inlet for violations of water quality standards. Some detailed data are available in the TMDL Report at the grid locations identified. Sources: Photo from Google Earth with labels added (photo date May 2013); Grid from TMDL Appendix G page G-21 with highlights added.

0.20 mg DO/L or more, at just one depth on just one occasion, the surface grid square is "flagged."

The flag can never be taken away, even if virtually all other DO's at all other depths beneath that surface square are far above the standard for the entire computer "year". If violations of the same magnitude occur beneath that square many times during the "year," or at many different depths at the same time, the surface "flag" remains the same. The only change that can occur after the surface is flagged is in its color, if a later violation is more serious than the earlier one. An illustration of this flagging process is shown in Figure 2.

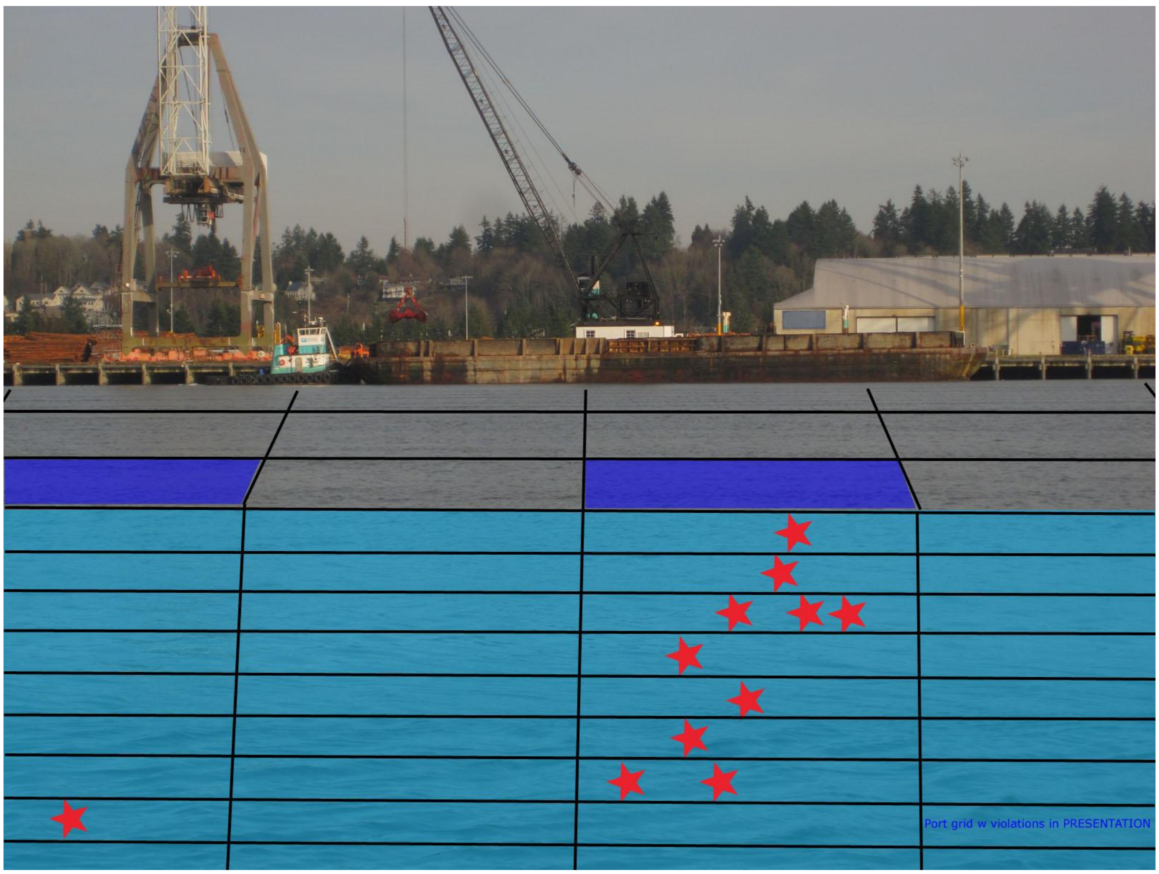


Figure 2. View looking east toward the Port Peninsula, with three rows of north-south grid squares on the surface and 9 depth layers seen in cross section below the surface squares. Say the WQ standard here is 5.0 mg DO/L in all grid cells, from surface to bottom. Suppose the calculated dissolved oxygen level drops to 4.80 mg DO/L in the 8th depth layer at left, just once during the entire computer "year." The surface square is flagged. Suppose multiple occurrences, all of calculated 4.80 mg DO/L levels, occur at different depths and times during the year in the water column to the right. The flag is not changed. However if a calculated violation lower than the worst earlier one occurs (say, 4.25 mg DO/L) the flag's color is changed to show the lowest DO ever seen at that place during that computer "year." *The flag color by itself gives no indication of how deep, or how often, or on what date(s) the violation(s) occurred, only the "worst case" level found during the simulation.* [For reference, grid site BI-5 in Figure 1 is in mid-channel just out of this picture to the right (south), grid site BI-4 is near the far shore just out of the picture to the left (north).]

Since the computer calculates DO's for every cell under every grid square in the entire Inlet, moving its "clock" forward by 6-minute time steps (the "iteration interval" of the model[iii]) through every day between January 15 and September 15, it is clear that every surface square that escapes being flagged has survived a fantastically rigorous assessment of its vulnerability to water quality degradation. It is also true that a square flagged just once for one six-minute violation is displayed identically [has the same "mug shot"] at the end of the simulation, with [as] a square flagged thousands of times for the same-level violation.

Data Produced by the Budd Inlet Model.

For comparison of the Lake's and Estuary's impacts on Budd Inlet, two sets of model simulations are conducted. The first envisions Capitol Lake impounded by a dam at its present location, the second envisions the dam "removed" (or so the computer is told) with a reconstructed tidal estuary replacing the Lake. These two sets are called the "Lake Scenarios" and the "Estuary Scenarios." Each set examines modern impacts on Budd Inlet, focusing first on sources stemming from watershed activities (logging, farming, urbanization, etc), then on wastewater treatment plant discharges, and finally both types of sources operating at the same time, to analyze the total impacts.

Although the computer generates and stores many kinds of data during each simulation, the Lake/Estuary Chapter of the TMDL Report mainly focuses on its calculated dissolved oxygen (DO) concentrations for evidence of impacts on Budd Inlet. The results of these calculations are shown in three formats:

1) Format 1. Aerial views of Budd Inlet highlighting areas "flagged" for DO water quality standards violations during the simulations;

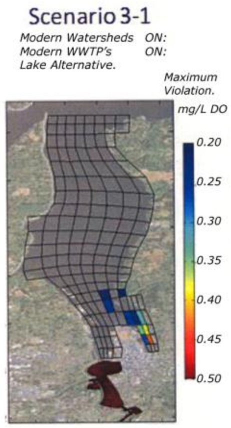
2) Format 2. Detailed time series showing maximum differences between DO levels for the Lake and Estuary Scenarios at a few selected sites;

3) Format 3. In one case, a view of Budd Inlet showing the maximum differences between DO levels for the Lake and Estuary Scenarios over the whole Inlet.

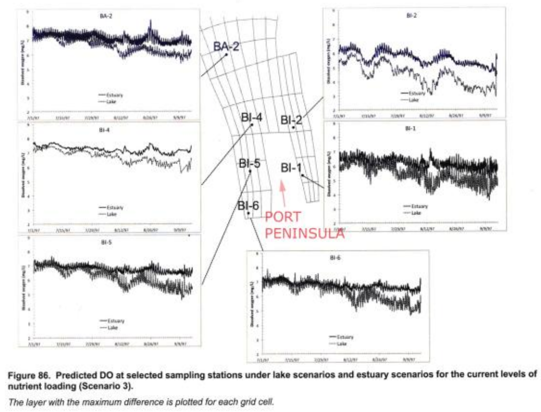
Examples of these data formats are shown in Figure 3. (Each of these figures is examined at a much larger scale later in the next sections of this report.)

In producing these findings, the computer is doing exactly what is has been programmed to do and presenting its findings in exactly the formats that best display its discoveries. However these findings are mostly irrelevant to the Lake/Estuary discussion and their presentation in these Formats is very prone to mistaken interpretation.

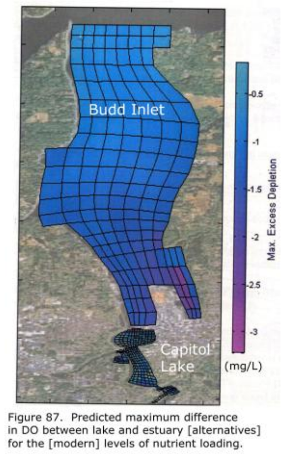
The findings shown in each of these data formats are analyzed in the next sections of this report.



Format 1. View showing sites flagged for water quality violations (and sites not flagged).



Format 2. Graphs showing changes and differences in DO levels from March to September at sites in or near West Bay and East Bay, comparing Lake & Estuary Scenarios.



Format 3. View showing maximum DO differences over all of Budd Inlet between Lake and Estuary Scenarios.

Figure 3. Methods of data presentation used in the Lake/Estuary Chapter, TMDL Report. All Formats show simulation results for 1997. Sources: TMDL's Figures 90c, 86, and 87 (L to R, pp. 206, 199, 200 in the L/E Chapter, slightly modified for illustration here).

Notes – Section 2.

[i] 168 grid squares as shown in Figure 84, TMDL Report.

[ii] The numerical water quality standards are as follows; 7.0 mg DO/L or more, "extraordinary" water, 6.0-7.0 "excellent," 5.0-6.0 "good," 4.0-5.0 "fair."

A "moving target" standard is used in areas where the water's DO level goes below the pre-assigned numerical standard, even in the Inlet's pre-modern "natural" condition. In such cases, the standard is whatever the natural level of DO would be at that season, depth, and place or the assigned numerical standard, whichever is lowest. Regardless, in all cases the computer compares the DO levels it calculates with some standard. The DO in the water must drop below the standard by at least 0.20 mg DO/L in order for the computer to "flag" that site.

The TMDL Report hints that the pre-assigned standard 5.0 mg DO/L is used everywhere in East and West Bays. The SPS DO Draft Model uses 5.0 for that region, 6.0 for most of Budd Inlet, and a "moving target" standard for the water around Priest Point Park. Figure 24 at the end of this report shows the Budd Inlet standards used by the S/CPS DO model.

[iii] Page 187, TMDL Report.

Section 3. Analysis of Format 1 Data and Presentations.

Figure 4 shows the results of two simulations, one with the Lake at the head of Budd Inlet and the other with an estuary taking the place of the Lake. Each of these shows the areas flagged for Water Quality Standards violations during their respective runs. In the Lake scenario, there are 10 flagged grid squares, all in or near East Bay or near the site of the LOTT outfall. The four squares flagged in the Estuary Scenario are all in East Bay.

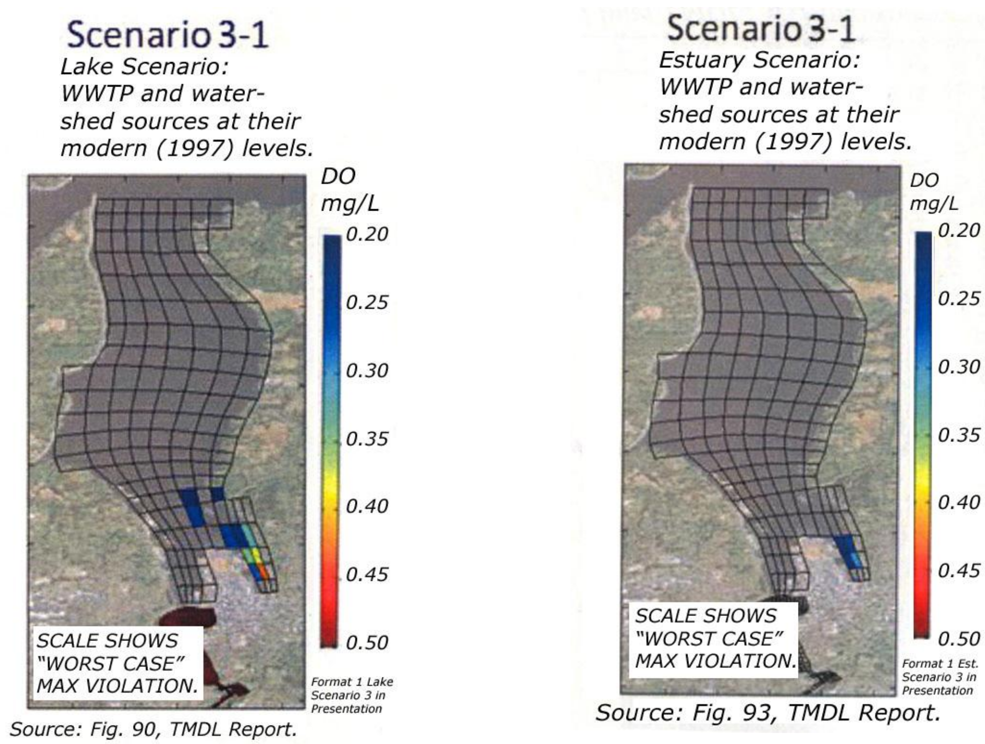


Figure 4. Grid squares flagged for Water Quality Standards violations in simulations with the Lake present and with the Lake replaced by an estuary. (Labels of the original Figures in the TMDL Report have been reformatted here for ease of reading. In the TMDL Report, the original Figure captions read "Predicted maximum violation of the DO water quality standard under the lake [estuary] scenarios.")

Three important features of all such data portrayals are as follows;

1) For both scenarios, the vast majority of the grid squares throughout Budd Inlet are not flagged. That is, despite the rigor of the computer's search for Water Quality Standards violations in every last cell, it found none in almost every case – nothing even so tiny as 0.2 mg/L.

2) One would expect that, if Capitol Lake were somehow degrading water quality in Budd Inlet, the lake's major effect would occur in West Bay, which receives the full first blast of water from the Lake. No effect is seen there in the Lake Scenario. Instead, all adverse indications are elsewhere.

3) Almost all of the violations in both Scenarios (9 of the total 14) are microscopically small and ecologically insignificant. All squares flagged dark blue show that *the worst predicted violation of the entire computer "year"* was only 0.2 mg/L – the smallest violation that the computer is set to detect. The worst of *all* flagged violations (Lake Scenario, East Bay) was somewhat less than 0.5 mg/L.

How small a change in DO is 0.2 mg DO/L? Natural water is hugely variable in the amount of oxygen it contains, from top to bottom, hour to hour, day to day. Figure 5 shows 0.2 mg/L in the context of changes in the amounts of dissolved oxygen in the bottom and surface waters in East Bay at grid square BI-1 from dates in April to September 1997, when the BI computer model was calibrated. The graphs show the computer's calculated values of DO, circles show measured values actually observed. In that variable system, 0.2 mg DO/L is a change so microscopic that it would be difficult to find in any real body of water.[iv]

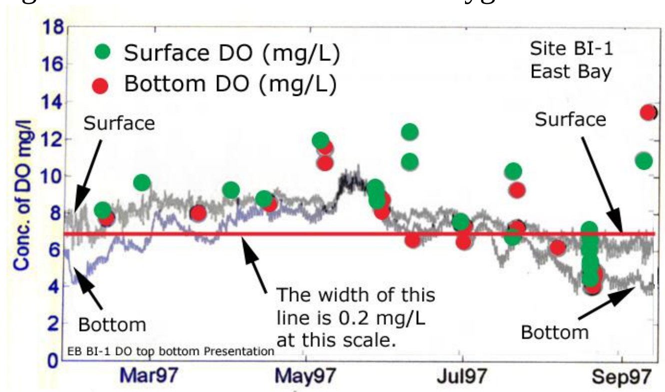


Figure 5. Predicted (graphs) and observed (circles) values of dissolved oxygen at the surface and bottom of East Bay, grid site BI-1, during the marine growing season of 1997. A line whose width is 0.2 mg/L is shown. A DO decrease of this size is the smallest "violation" flagged by the computer. Source: composite of TMDL Appendix G2 figures BI-1 KB and KT, pp G2-13 & 15.

This is a prime example of the model's ability to direct our attention to grid squares that are most vulnerable to water quality degradation even before changes there become measurable or noticeable. It is *not* showing us a "water quality problem."

How long do the small violations shown in Figure 4 persist? The TMDL Report uses other Format 1 Figures to attempt to answer this question (Figures 91 and 93, TMDL). Unfortunately, the scale on these Figures is ambiguous and doesn't permit interpretation with certainty.[v]

Almost all scenario simulations show the Lake outcome with more flagged grid squares than the Estuary outcome. There are several possible reasons for this (addressed in Sections 8 and 9 below). One is that the Lake does indeed create more vulnerable (flagged) areas than does the Estuary. Another arises from the fact that switching the simulated south end of Puget Sound between Lake and Estuary conditions requires introducing structural model changes having little or nothing to do with water body properties. Those changes, not inherent properties of the lake or estuary, could be the reason for many differences in the outcomes. (Specifically, there is a difference in the physical widths of the discharges to West Bay in the two scenarios.) Finally, there may be a fundamental error in the way in which the baseline for the Lake simulations – "Lake Scenario 1" – was constructed. That possibility is discussed in Section 9.

In conclusion, the Format 1 data presentation invites the interpretation that the areas flagged have "water quality problems." For the reasons given above, that would be a mistaken conclusion. A definition of "water quality problem" that has ecological significance and another way of looking at the "interpretation mistake" is seen by analyzing data presented in Formats 2 and 3, in the sections that follow.

Notes -- Section 3.

[iv] A change of 0.2 mg/L is the amount by which the meter on a DO-measuring device fluctuates with every passing second as the water in contact with the probe goes streaming by – that is, it is at the level of measurement "noise" in the natural system.

[v] The scale is labeled "days/layers" with values ranging from zero to 90. If this is a "worst case" portrayal, as is true of virtually every other Format 1 Figure, then a violation of 0.2 mg/L in the bottom depth layer occurring all day every day for 90 days would be rated "90" – but so would a violation of 0.2 mg/L occurring for just 10 seconds in each of 10 depth layers once every day for 9 days – a total of just 15 minutes' miniscule violations. A few sentences that describe "duration" of the violations (p. 205, TMDL) do not resolve this ambiguity.

Section 4. Analysis of Format 2 Data and Presentations.

Figure 6 shows one of six similar graphs portrayed in Figure 86 of the TMDL Report. (All six are shown in miniature in Figure 3, Section 1 above.) This example of data in Format 2 shows how dissolved oxygen at site BI-5 in West Bay changes with time during part of the computer "year". The time span actually shown (July 1 – September 15) is about half of the marine growing season in Budd Inlet, when longer days make possible explosions of phytoplankton growth in the water. The upper graph curve shows the dissolved oxygen level at some depth every day from July 1 to September 15 for the Estuary scenario, the lower curve shows the DO level every day at the same depth for the Lake scenario.

With a few features added to the TMDL graph by me, Figure 6 shows the following;

> 1) A "water quality *standards* violation" is not the same thing as a "water quality *problem*;"
>
> 2) The TMDL graphs comparing Lake and Estuary show only two or three small *WQ standard violations* for the Lake Scenario occurring at some unspecified depth(s) on only a few days during the 77-day interval[vi];
>
> 3) The DO concentrations shown in Format 2 are always much higher than the concentrations at which real water quality problems begin.

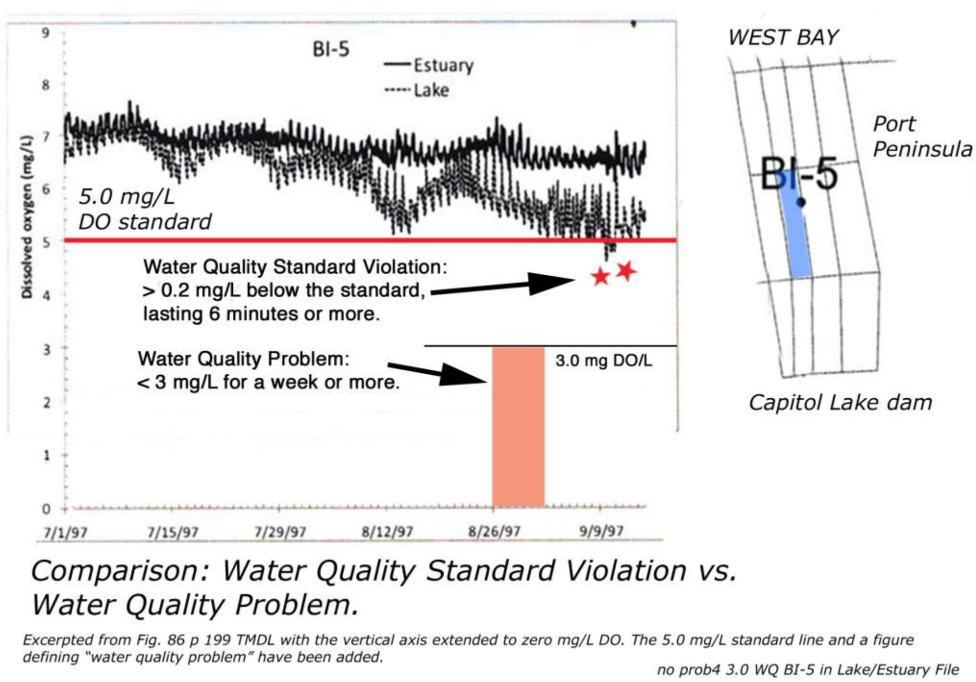


Figure 6. Calculated daily differences in DO levels between the Lake and Estuary Scenarios at grid square BI-5, July 1–September 15 1997, shown in Format 2. The difference on each day is the vertical distance between the two curves on that day.

In Figure 6, the curves show the calculated DO concentrations at some depth for the Lake and Estuary scenarios, each day. What depth? At whatever depth the difference is greatest on each day at site BI-5. The depths are probably not the same from day to day; we are not told in the TMDL Report exactly which depths they are. The only thing we can be sure of is that the differences shown by the graphs are the biggest differences of all; nowhere in the water column, each day, is there a bigger difference between "Lake" and "Estuary" DO's than the ones shown.

A Water Quality (WQ) *problem* occurs when DO concentrations in the water drop to a low value that causes aerobic organisms – crabs, fish, clams etc.– to experience respiratory distress. Estuarine organisms are "accustomed" (= "adapted") to such conditions and if the low DO concentration persists for only a day or so they can "hang in there" and resume normal life when the DO level increases again. If the water remains low in DO for a few days, mobile organisms may begin to move about and may escape to higher-DO water.[vii]

The level to which DO must fall to begin to stress organisms depends upon many factors – water temperature, presence of toxins (say, metals), time of year, whether or not local organisms are adapted to occasional low DO in their usual circumstances – but the critical concentration is usually near 3 mg DO/L. At 2 mg/L, stress on the organisms starts to become acute. If those conditions persist for a week, then a true low-oxygen crisis bears down on the community and some organisms may die.[viii]

A week-long period with a DO-level of 3 mg/L has been added to Figure 6. The Lake and Estuary DO levels are always 1.5-2.0 mg/L higher than that threshold, in this and every other Format-2 graph in the TMDL Report. Nowhere do the curves even remotely approach a level and duration at which a true water quality problem would be created.[ix]

One's first impression from Figure 4 (Format 1 data, previous section) is that the computer has shown *water quality problems* in East Bay. This is an intuitive misinterpretation of what the computer is telling us. The figures show us *water quality standard violations* that resulted in calculated DO's in those areas ranging from 4.8 mg/L (most cases) to 4.5 mg/L (lowest value) by the end of the growing season. Those colored squares draw attention to those places as *areas vulnerable to WQ degradation* – not areas experiencing ecological Water Quality problems.

In reality, parts of East and West Bays do indeed experience true, severe seasonal water quality problems. Figure 7 shows the results of measurements of DO made from a dock on the east shore of West Bay opposite grid square BI-5, obtained by a colleague and me on September 14, 2013.[x] Unlike the TMDL data presentations, this one shows the DO data in a conventional format in which one can see what's happening at all depths – interpreted as follows.

On September 14 2013 at the dock mentioned, dissolved oxygen was highest at the surface (nearly 6.0 mg/L) but decreased with depth, then increased, then decreased all the way to the bottom 4.5 meters below. DO dropped below the critical 3 mg/L threshold about 2 meters below the surface, then to 2 mg/L and lower about 3.5 m below the surface. If the water deeper than 2 meters were to remain at 3 mg/L or lower for the next week – or if it had already been at 3 mg/L or lower during the week previous to Sept. 14 – then that dock site and the deep water organisms living there would experience a true life-threatening water quality problem.

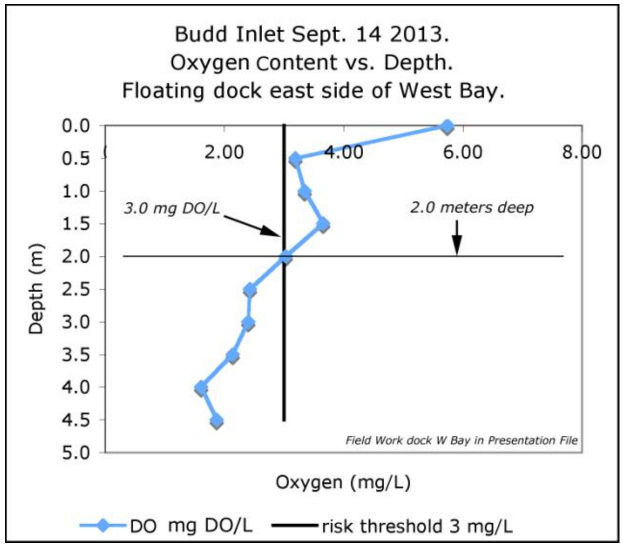


Figure 7. Decrease in dissolved oxygen with depth at a site in West Bay, showing a potential water quality problem below 2 meters deep. Observed Sept. 14, 2013.

There are big differences in calculated DO levels between the "Lake" and "Estuary" situations as shown in Format 2 in Figure 6. In this case, *really* big differences in DO's, not just miniscule 0.2 mg/L differences.

Why?

The explanation is probably that Capitol Lake exerts a powerful beneficial effect on Budd Inlet's water quality. This likelihood is analyzed in detail in the discussion of Format 3 (Section 5, below).

Notes -- Section 4.

[vi] The author is surprised that area BI-5 is not flagged (in Figure 4 Lake Scenario and in other Format 1 Lake figures) for the small violations shown in this graph. Perhaps the violations are less than 0.2 mg/L?

[vii] Mobile organisms "may" escape – they are often unable to tell whether they are moving into a zone of lower or higher DO and may make things worse for themselves.

[viii] Organisms living in water that is naturally reduced to low oxygen levels for long intervals are often, themselves, adapted to surviving long stressful exposures. Their presence can indicate that long-lasting low-DO periods occur in those waters even under natural conditions. Recalling from my memory only, there is at least one such organism in Puget Sound. As I recall, a tiny clam *Axinopsida sericata* is one such animal. As I recall, it is found in the deep water of the Bend of Hood Canal -- but not in West Bay, Olympia. (I made sporadic efforts to find it in Olympia Harbor, without success, about 2000 – 2003.) If someone can confirm or amend this I'd appreciate it!

[ix] It is surprising that none of the computer simulations reported in the TMDL Report predict the real water quality problems that occur from time to time in East and West Bays. More is said of this later in this report. [Specifically, to catch events that don't occur every year, simulations need to be done for more than one year.]

[x] This Figure is called a "vertical profile" of dissolved oxygen in water. It is in a conventional format that is used and understood by aquatic researchers everywhere.

Section 5. Analysis of Format 3 Data and Presentations.

At first glance, Figure 87 of the L/E Chapter seems to present powerful evidence that Capitol Lake has a negative effect on water quality throughout all of Budd Inlet (Figure 8). It shows the computer's calculation that, at some (unspecified) depth under every grid square, the Inlet would have less dissolved oxygen under the Lake Scenario than if an Estuary were to replace the Lake. The differences are significant – mostly about 1 mg/L but approaching 3 mg/L in the most extreme cases. As in the other Formats portraying the computer's findings, the "worst case" is shown here for each grid square. The depths at which these big differences occur are not shown and are probably not the same everywhere, nor are the dates, but we can be sure that there are no bigger differences at any other depths at any other times under each grid square.

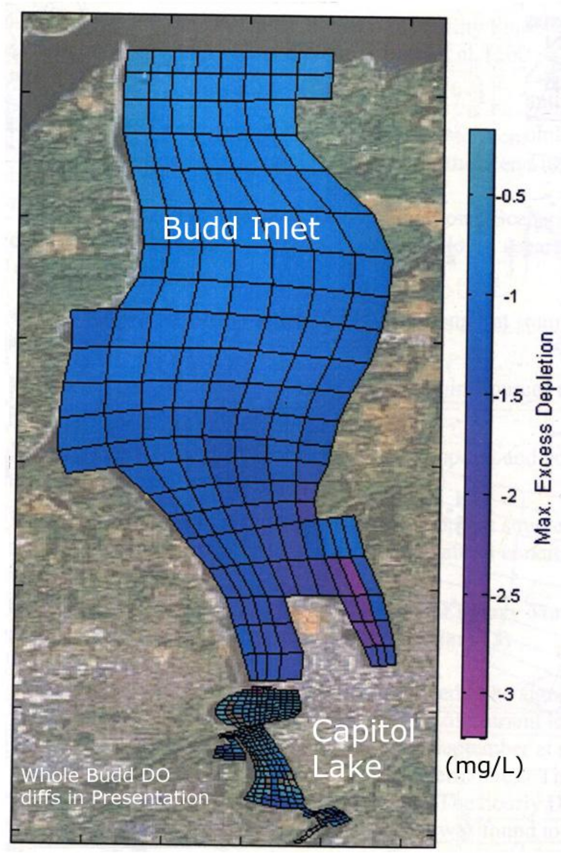


Figure 87. Predicted maximum difference in DO between lake and estuary scenarios for the [modern] levels of nutrient loading.

Figure 8. Budd Inlet with reduced O2 levels shown in all grid squares, all lower in the Lake Scenario than in the Estuary Scenario. Source: Fig. 87 in TMDL report with some label clarification.

This finding almost certainly results from a beneficial effect on Budd Inlet by Capitol Lake that the computer is not set to recognize. Understanding it begins with a look at how water moves in Budd Inlet. The explanation is detailed and it may be helpful to see where it is going before starting on it.

In a nutshell, the Deschutes River water is high in nutrient content; the water discharged by Capitol Lake has low nutrient levels. High nutrient water discharged into Budd Inlet in the Estuary Scenario would fuel explosive growth of phytoplankton with huge additions of dissolved oxygen to the water – all of this near the surface. The excess oxygen would escape into the air, clouds of phytoplankton would settle into deep water and decompose, lowering oxygen levels near the bottom. The net effect on the ecosystem of the "nutrient party" at the surface would be to lower the DO level near the bottom – the "hangover," so to speak -- with consequent stress on the organisms there. A low-nutrient discharge from Capitol Lake would suppress this effect, resulting in less oxygen at the surface (where it is almost always abundant) but more at the bottom (where it is almost always scarce).

The computer knows nothing of all this. It is set to look for the biggest differences it can find between DO levels in the Lake and Estuary Scenarios, and finds them – right at the surface, I expect, where the extra oxygen helps nothing. The deteriorating DO situation at the bottom caused by this extra surface oxygen production is overlooked.

To illustrate, consider the following.

Figure 9 shows the major internal pattern of water movement throughout the Inlet. The example is in West Bay, but this pattern of movement (known as “estuarine circulation”[xi]) prevails throughout all of Budd Inlet and indeed throughout almost all of the Salish Sea and Puget Sound, from Neah Bay through the Strait of Juan de Fuca to Olympia.

A huge non-stop flow of low-salinity water moves slowly outward at the surface toward the Pacific Ocean and is balanced by an inward flow of high-salinity water of nearly equal size moving along the bottom. (In West Bay, the lower-salinity surface flow is about 20 times the size of the Deschutes River.) Both surface and bottom flows are driven by the incoming fresh river water at the head of the estuary. Tidal changes are not responsible for these flows, which would occur even if there were no tides at all.

The bottom water entering Puget Sound from the Pacific Ocean is typically low in dissolved oxygen and high in nutrient nitrogen content. As it moves toward the heads of estuaries, some of this bottom water is dragged upward and into the outgoing surface flow, feeding nutrients to the surface water. The landward and upward movements of nutrients in this way are colossal. They dwarf the amounts of concern to us that arise from human activities. For example, local deliveries of nitrogen nutrients to Budd Inlet are on the order of 572 kg N/day (representative summer LOTT + Deschutes River discharge values).[xii] The flow of nutrients from natural- + human-sources to the north into the mouth of Budd Inlet along the bottom carries about 8348 kg N/day (see Figure 1)[xiii]. By the time this huge bottom flow reaches waters off Priest Point Park, most of its nitrogen load has risen to the surface, leaving “only” about 1670 kg N/day to continue its southward journey, mostly into West Bay.[xiv]

This massive inward and upward movement of nutrients is the reason why estuaries are such biologically productive waters.

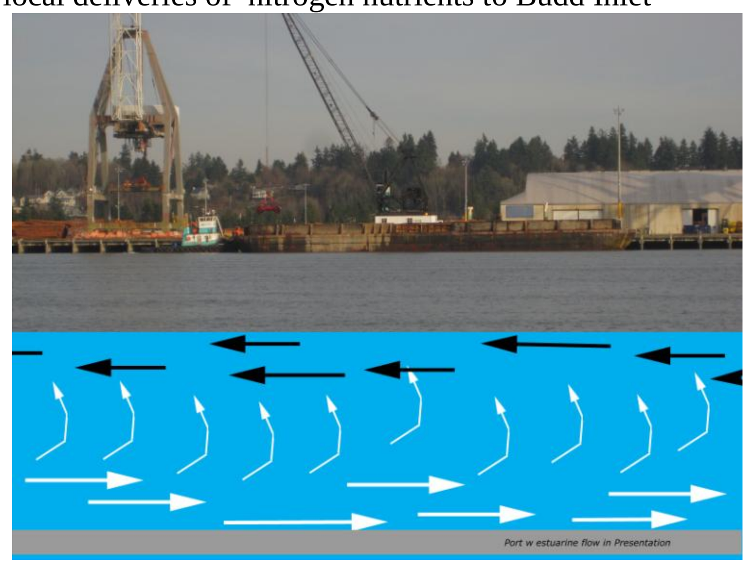


Figure 9. Surface water (dark arrows) flows outward from its river source to the ocean; deep water (light arrows) flows inward from the ocean to the head of the estuary. Water from the deep flow gradually mixes upward into the surface flow and exits the estuary – a pattern known as “estuarine circulation.”

As the nutrients rise to the surface, they are used by single-celled plants (phytoplankton) that grow, multiply, photosynthesize and release oxygen into the water. The constant rise of nutrients from the dark deep waters below into the lighted surface waters replenishes the nutrients that have been used up and sustains the exuberant growth of the phytoplankton. Any nutrients added by human activities amplify this process. The numbers given above – about 1670 kg N delivered daily to East and West Bays from the bottom with another ~ 572 kg N/L added daily by Budd Inlet natural and anthropogenic sources (if no Lake were present) – suggest that the local sources might raise the total daily nutrient load to 2242 kg N/day, of which the Budd Inlet sources would be responsible for some 25% of the total.

One result of this "nutrient forcing" is a huge production of oxygen in the upper waters of the Inlet. The nutrients – primarily nitrate (NO_3^-) and nitrite (NO_2^-) – are the "fertilizers" that enable explosive population growth of single-celled plants, which produce and release vast amounts of oxygen.

Exuberant phytoplankton growth at the surface has a "dark side," however. The plant cells and/or their remains eventually end up in deep water, either by sinking or by being carried downward by the small herbivores (zooplankton) that eat and assimilate them. Plant matter that reaches the bottom in one form or another decomposes. The bacteria that decompose it consume oxygen – *lots* of oxygen. The result is that the exuberant oxygen production at the surface comes at a price – a decrease in dissolved oxygen levels at the bottom – somewhere, sometime.

The bonanza of excess dissolved oxygen at the surface does little to help the rest of the aquatic community. The fate of most of the oxygen produced there is to diffuse out of the water and go back into the air. Physical processes are usually not able to mix it downward far enough to alleviate the low-oxygen conditions existing in deeper water, especially during summers.

Where is the "somewhere else" that pays the price? The seaward drift of surface water carries the phytoplankton in the Inlet toward the north. The organic matter produced by them usually sinks farther out in the inlet than where it was produced, most of it (probably) outside Budd Inlet into deeper waters of the South Sound. Some of the lower DO (and recycled nutrients) released out there is carried back into Budd Inlet in the deep flow, but the effects are much diluted and dispersed when returning from far away. *The effect on Budd Inlet's oxygen of adding nutrients to the water is likely to be a marked increase in DO at the surface and a small or moderate decrease in DO in the deeper water somewhere nearby. The net effect of high nutrient input on the whole system's water quality is negative; excess DO at or near the surface is a sign of water quality imbalance, not ecosystem health.* That is the symptom that the BI Model was not set to recognize.

Figure 10 shows a "vertical profile" of the distribution of water temperature, salinity and dissolved oxygen obtained by University of Washington researchers in August, 1958.[xv] The location is "Buoy 12" in West Bay, west of the Port docks. The graphs show that the water temperature at the surface is about 20 degrees C and drops to about 15 deg C near the bottom in the pattern shown. Water salinity shows a mirror image of the same pattern, increasing from about 26 ppt at the surface to about 30 ppt near the bottom. Dissolved oxygen is at about 12 mg/L near the surface, declining in deeper water in a similar pattern.

Interpretation is as follows. The surface layer is fresher and warmer than the bottom layer. (Recall that this site is right in the main flow of water out of Capitol Lake, which is causing this pattern.) All curves "break" (change direction) at about two meters depth. That is a likely indication that the outward surface flow shown in Figure 9 takes place in the upper two meters of water and that the deep inward flow is below that depth.

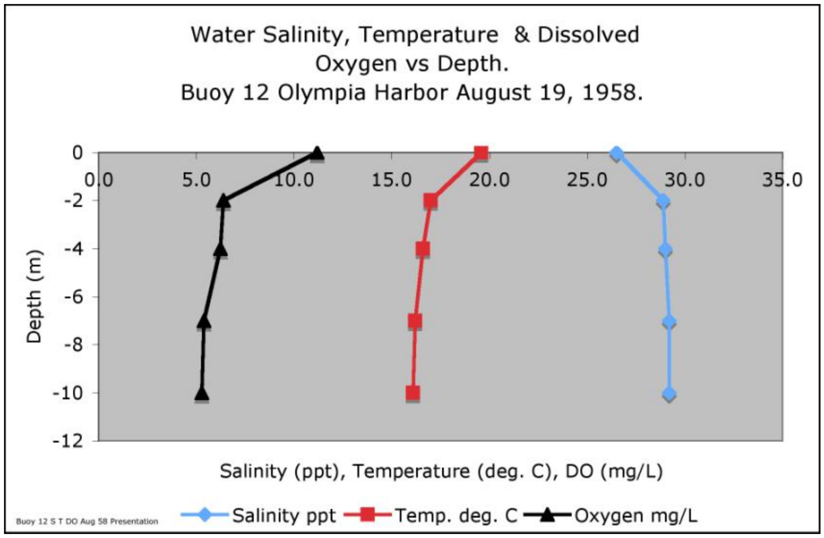


Figure 10. Vertical distribution of West Bay water temperature, salinity, and dissolved oxygen at Buoy 12 in Olympia (WA) Harbor. August 19, 1958.

Figure 11 shows two vertical profiles of dissolved oxygen at the Buoy 12 site, one of them the same curve shown in Figure 10 (August 1958), the other from August of 1957. The 1957 curve is amended here for illustrative purposes. The WQ DO standard at this site, 5.0 mg/L at all depths, is shown as a vertical line, indicating that neither curve would have resulted in a "flag" at that site in the Format #1 presentation shown in

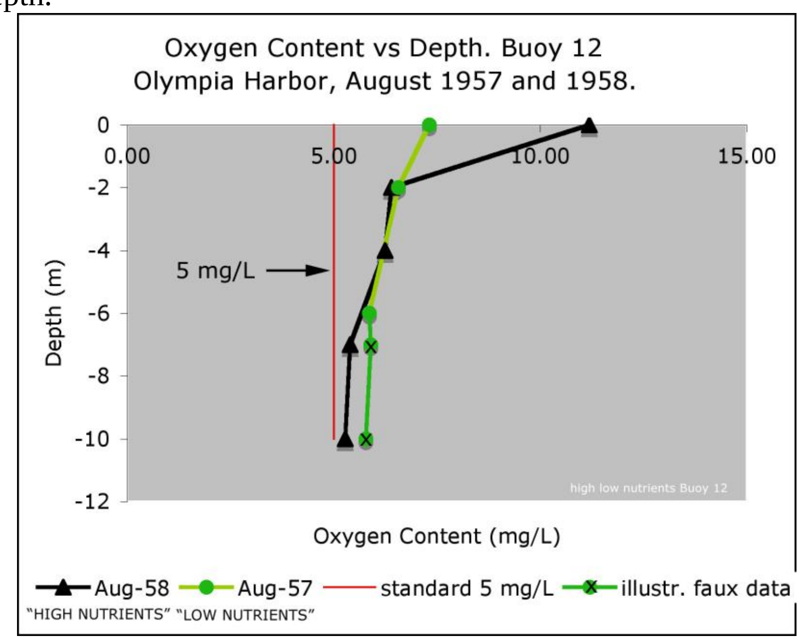


Figure 11. Vertical distributions of dissolved oxygen at Buoy 12 in Olympia (WA) Harbor. August 2 1957, and August 19 1958, with 5 mg/L DO level indicated. Deepest two 1957 values are calculated for illustrative purposes, not observed data. See Text.

Figure 4 above.

In 1957 the UW researchers obtained DO measurements at only three depths; surface, 2 meters, and 7 meters. I have extended the 1957 curve to 10 meters depth by adding two artificial "values" at 8 meters and 10 meters. The artificial values were calculated by adding 0.5 mg/L to the 1958 observed values at those depths. The result is a pair of vertical profiles containing (mostly) real data that mimic what we would see in a high-nutrient and a low-nutrient situation. Specifically, a low nutrient situation would result in a profile like that for 1957; a high nutrient situation would result in a profile like that for 1958.

The computer probably "saw" all of this. But it was not programmed to call attention to it. Instead, it was programmed to find the biggest difference between the Lake and Estuary scenarios' DO's at any depth and ultimately report that in Figure 87 of the TMDL Report. As seen in the two graphs in Figure 11, the biggest difference (ie, horizontal distance between the two curves) is right at the surface. At other depths in this example the mathematical differences are much less. However the ecological difference can be enormous. During some summers, exuberant phytoplankton growth in nearby Eld Inlet creates such clouds of sinking decomposing phytoplankton that almost all oxygen at the bottom is used up and oysters and other shellfish die. [Pers. Comm. Dan Cheney].

Instead of showing a problem, the Format 3 display almost certainly shows that the Lake is protecting West Bay from eutrophication by flooding the surface with low-nutrient water whereas an estuary of the Deschutes River would drive the ecosystem toward oxygen depletion in the bottom waters.

There is an easy way to show whether or not this hypothesis is correct. That is, for each of the labeled grid sites shown in Figure 1, search the stored simulation data to find the date on which the biggest difference between Lake and Estuary DO's occurred. For that date, show the whole vertical profile of the dissolved oxygen content of the water for each scenario and find the depth at which the difference between the two profiles is greatest. If those depths-of-greatest-difference are at or near the surface, then it's settled; Capitol Lake helps Budd Inlet resist eutrophication. If the greatest differences are elsewhere -- in mid-water, or at the bottom, or scattered at random among the water columns, identifying the mechanism would be less straightforward.

Notes -- Section 5.

[xi] See TMDL Appendix G, p. 49, for a description of estuarine circulation.

[xii] 572 kg N/day from Tables 35 & 36, TMDL, Scenario 3. Of this daily load, 327 kg N/day are from "natural" watershed sources, 92 kg/day are from the summer LOTT discharge, and 153 kg/day are added by human activities to all watersheds around Budd Inlet; however the vast majority of watershed nitrogen is carried in the Deschutes River and Percival Creek.

572 kg/day is the amount that would go into Budd Inlet daily if the Lake were not there. The Lake reduces the Deschutes and Percival nitrogen discharges by 40% or (usually) much more.

[xiii] See Table 35 "Open Boundary" TMDL L/E Chapter p. 202, and TMDL Appendix G p. 49.

[xiv] I have calculated 1670 kg N/day from the following data on page 49 Appendix D. The bottom flow entering Budd Inlet from the north is about 500 cubic meters of water per second. By the time it reaches Priest Point, that flow is said to be 100 m^3/sec. Thus 80% of the water carrying 80% of the nitrogen load that entered Budd Inlet has risen to the surface by the time the bottom current reaches Priest Point, as shown in Figure 9. The 20% of bottom nitrogen remaining is (0.2)x(8348) = 1670 kg N/day reaching Priest Point. … "mostly into West Bay …" The bottom inflow is driven by the surface outflow, almost all of which is due to the Deschutes River at West Bay.

[xv] Source: Collias, E. E., J. Dermody and C. A. Barnes. Physical and Chemical Data for Southern Puget Sound. August 1957 – October 1958. University of Washington Technical Report No. 67. UW Press, 1962.

Section 6. Most Capitol Lake Water Doesn't Move Eastward to East Bay – It Flows Northward.

In order for water released at the dam to have an effect (negative or positive) in or near East Bay – where the WQ Standard violations (Figure 4 above) and the largest DO differences between the "Lake" and "Estuary" Scenarios always occur, the water must turn eastward as it flows out of West Bay, pass the end of the Port Peninsula and go to the entrance of East Bay. Data in TMDL Appendix G suggest that this doesn't happen. In July 1997 at least, surface water exiting West Bay proceeded straight northward hugging the west shore as shown by computer model calculations and field observations. If that is usually the case, Capitol Lake can't possibly cause problems in East Bay; the sources of those problems must lie in or near East Bay itself.

Figure 12 shows the salinity at the surface of West Bay in grid square BI-5 (west of the Port docks, see Figure 1 above) from a date in April to about September 15, 1997, as calculated by the computer. The calculated salinities (dark lines) vary daily between values lower than about 12 parts per thousand (ppt) to about 25 ppt. The erratic up- and down swings are caused by tidal changes that flood the site with saltier water when the tide is rising and allow fresher water from the direction of the dam to flow through it when the tide is ebbing.

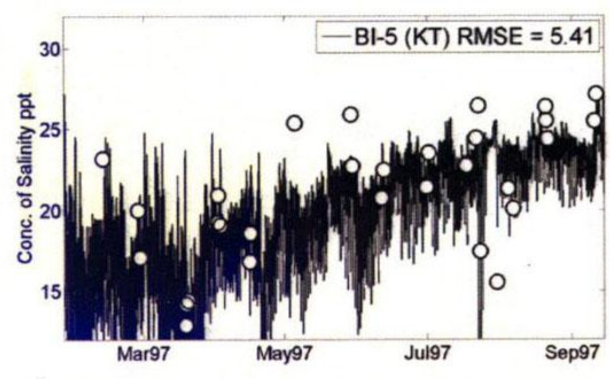


Figure 12. Calculated (graph) and observed (circles) values of surface salinity in grid square BI-5, West Bay, April–September 1997. Source: Figure G33 TMDL Appendix G p. 47.

Between July 22 and August 7 1997, Capitol Lake was completely drained. The effect of this can be seen in this graph. The computer's calculated surface salinity plunged from a high of about 24 ppt to a value lower than 12 ppt, literally overnight. For the next few days following the release, calculated surface salinities returned to a high level and remained there, then resumed their typical up and down fluctuations for the rest of the computer's "season." Field measurements (circles on the graph) confirmed that surface salinity dropped dramatically here during this episode.

The data of Figure 12 with the comparable graphs of surface salinity for other sites are shown in Figure 13. In that Figure, abruptly dropping surface salinities are seen in both the computer calculations and in the field measurements for sites in West Bay (BI-6, -5, -4), and at site BA-2 north of West Bay. The comparable data for the entrance and interior of East Bay (BI-2 and 1, respectively) show only a feeble indication of this event, at best. At the site farthest out in the Inlet in this Figure (BB-2), there was no sign of a salinity decrease either in the calculated predictions or in measurements. (For reference, BA-2 and BI-2 are respectively about 10,000 and 7000 feet distant by water from the dam.)[xvi]

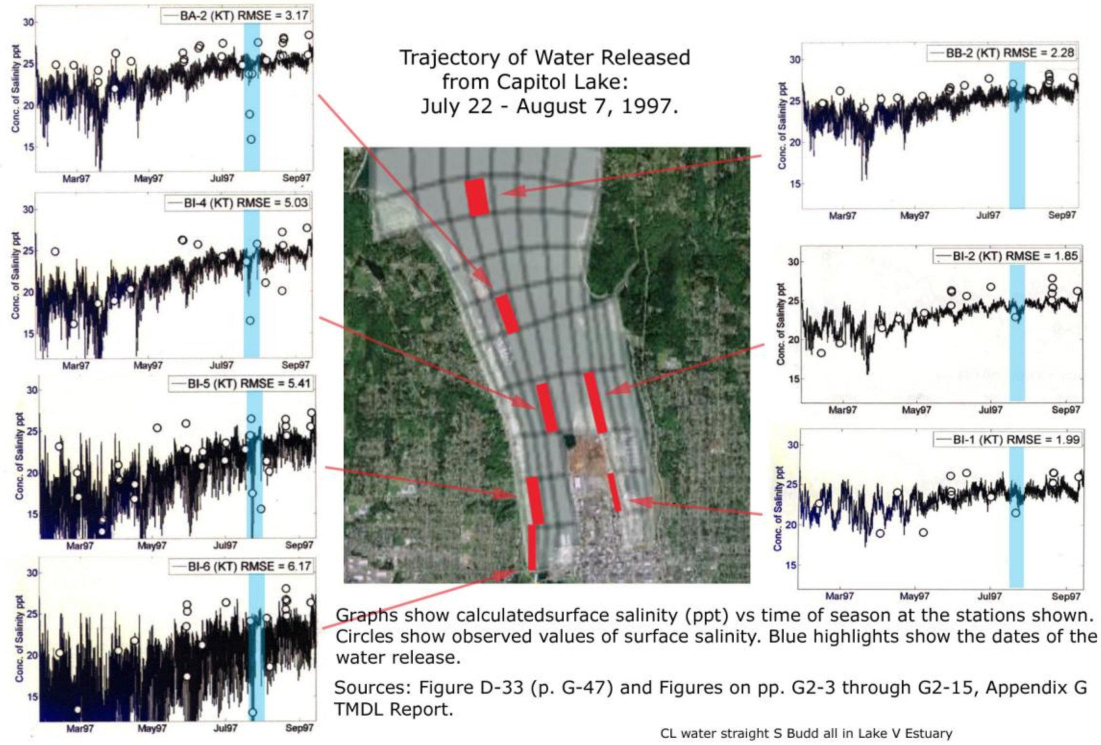


Figure 13. Surface salinities at sites in southern Budd Inlet showing movement of a fresh water release from Capitol Lake July 22–August 7, 1997. Sites along the west shore (left) show a strong abrupt depression of surface salinity on the dates of the release (highlighted). Sites near East Bay (BI-1 & 2) and mid channel north of Priest Point Park (BB-2) show no signal or at most a weak suggestion of this event.

"Strong flow north, feeble flow east;" this same pattern is seen in other data calculated by the computer, specifically its estimates of "Carbon Biological Oxygen Demand" (CBOD) at the same sites.[xvii]

Figure 14 shows the CBOD graphs calculated for the sites shown in Figure 13. In a nut-shell, they show the same pattern as do the surface salinity graphs, with some expectation of a small CBOD spike at the entrance of East Bay (BI-2), perhaps a hint of a weak spike north of Priest Point Park (BB-2) and none in the interior of East Bay (BI-1).

Unlike measuring salinity, measurement of CBOD is a laborious process. No observed values are shown in the source Figures in the Appendices and perhaps none are available for comparison with the graphs. But the graphs make it clear from the way in which the Budd Inlet Model handles both salinity and CBOD that the Model does not move water from the entrance of West Bay into that of East Bay.

There are other considerations. The surface outflow from West Bay is partially blocked from access to East Bay by a weak "curtain" of rising fresh water from the 1000-foot LOTT outfall extending northward from the Port Peninsula between grid squares BI-4 and BI-2. The feeble northward surface flows from Moxlie and Mission Creeks (respectively at the head and mouth of East Bay) further impede any movement of West Bay surface water toward and into East Bay. Capitol Lake water doesn't go there. By direct transfer at least, the Lake is not responsible for any of East Bay's water quality problems or water quality standards violations.

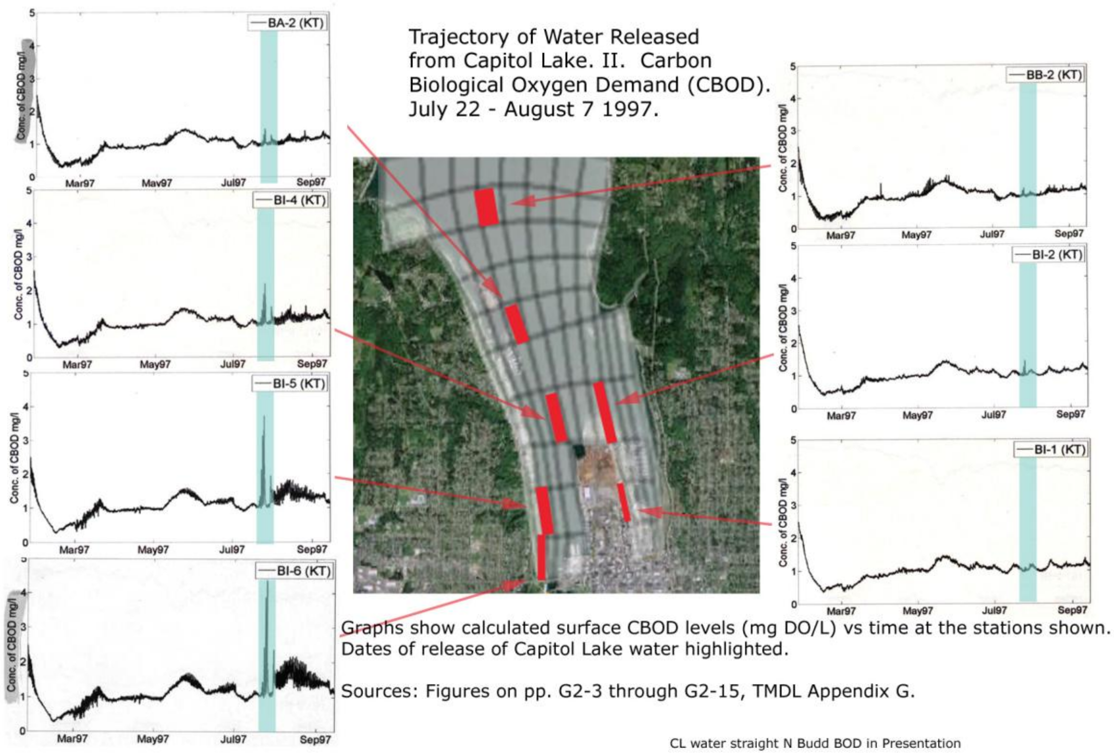


Figure 14. Surface values of Biological Oxygen Demand at sites in southern Budd Inlet showing movement of a water release from Capitol Lake July 22–August 7, 1997. Sites along the west shore (left) show strong-to-weak "spikes" in CBOD on the dates of the release (highlighted). The entrance to East Bay (BI-1) shows a weak spike in BOD, as may a mid channel site north of Priest Point Park (BB-2). The site in East Bay (BI-1) shows no signal of this event.

Notes -- Section 6.

[xvi] Distances dam to sites; measured on Google Earth aerial photo of southern Budd Inlet.

[xvii] In addition to fresh water, draining the lake added an uncharacteristic rush of organic matter – fragments of plants, organic carbon particles and the like – to West Bay. This material, beginning to decay there, uses up oxygen as bacteria consume it. The amount of oxygen that this extra material will use up is its "BOD". This is measured in mg DO/L.

Section 7. Does the Model Reproduce Capitol Lake's Nutrient Capture Property?

The Deschutes River is loaded with nutrient nitrogen. As described below, Capitol Lake removes between 40% and 90% of the river's nitrogen during the marine growing season before releasing the water to Budd Inlet. The operation of this gigantic "water purificat-ion effect" by Capitol Lake is the single most important difference between the Lake and Estuary Scenarios with regard to water quality in Budd Inlet. Unfortunately, there is no definite statement in the TMDL Report that the Budd Inlet Model included that effect. The following describes the Lake's capture of nutrient nitrogen and looks at evidence that the Model actually simulated this phenomenon.

The main source of fresh water entering Budd Inlet in either Lake or Estuary scenario is the Deschutes River. At present the river's water enters Capitol Lake at the Lake's South Basin, flows northward through an extensive "filter" of large plants ("macrophytes") in the Middle Basin, then exits from the North Basin into Budd Inlet at the Fifth Avenue dam (Figure 15). A second freshwater source entering the lake is Percival Creek, which enters the north end of the Middle Basin from the west.

Figure 16 shows the volume of flow of the Deschutes River in 2008, measured just upstream from the point where it enters Capitol Lake at the South Basin.[xviii] The flow of Percival Creek is not included in this inflow measurement. (The Creek's volume input is about 10% that of the Deschutes River.) Figure 16 also shows the volume of flow out of Capitol Lake into Budd Inlet during spring and summer, measured at the dam. This flow includes the water from both the creek and the river.[xix]

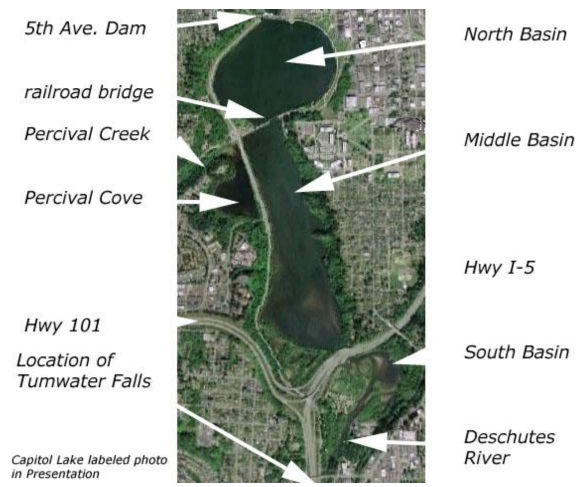


Figure 15. Capitol Lake and local landmarks. Tumwater Falls is just outside this image to the south. Budd Inlet is just to the north of the 5th Avenue dam.

Both the river and the creek have high nutrient nitrogen contents. Nitrogen is the "fertilizer" that plants can use and that can cause water quality problems if it becomes too abundant.[xx]

Figures 16 - 19 (next page) give a nutshell presentation of the nitrogen-cleanup action of Capitol Lake. Figure 16 shows monthly Deschutes River flows measured upstream from the Lake (inflow) and total flows at the dam (outflow) as mentioned. Figure 17 shows the nitrogen concentrations in those respective waters. Multiplying each monthly N concentration by the monthly volume of flow gives Figure 18 showing the actual amounts of nitrogen (in thousands of kg/month) entering and leaving the Lake each month.[xxi] Figures 17 and 18 both show the dramatic reduction of nutrient nitrogen by the Lake before the water reaches the dam. Finally, Figure 19 shows the quantities of nitrogen nutrients kept out of Budd Inlet by the Lake during each month of that summer. (These numbers are the differences between the "incoming" and "outgoing" values in Figure 18.)

One thousand kilograms is a metric ton (= "tonne" = 2,200 lb). Thus, in June 2008, Capitol Lake prevented 4.20 metric tons of nitrogen (in the form of nitrate and nitrite) from entering Budd Inlet (Figure 19). As a way of visualizing this, imagine yourself on the 5th Ave. Bridge on June 1 this summer. Piled around you are 1,850 50-lb bags of fertilizer whose N content is 10% nitrate.

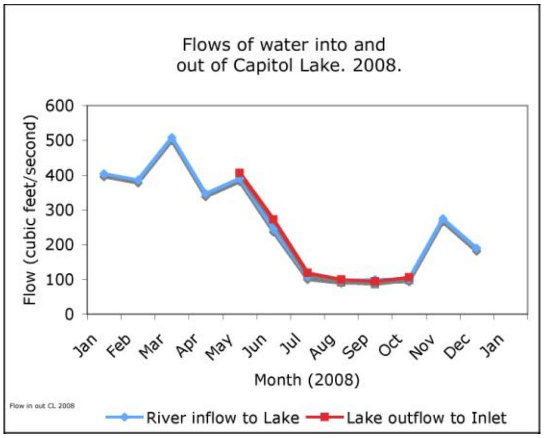


Figure 16. Volumes of water discharged by the Deschutes River to Capitol Lake and by the Lake to Budd Inlet each month (inflow) and summer months (outflow). 2008.

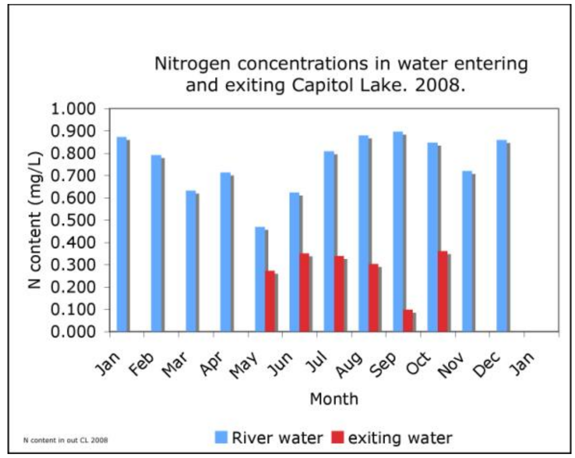


Figure 17. Nitrate + nitrite concentrations in the waters entering (year long) and exiting Capitol Lake (summer months) each month. 2008.

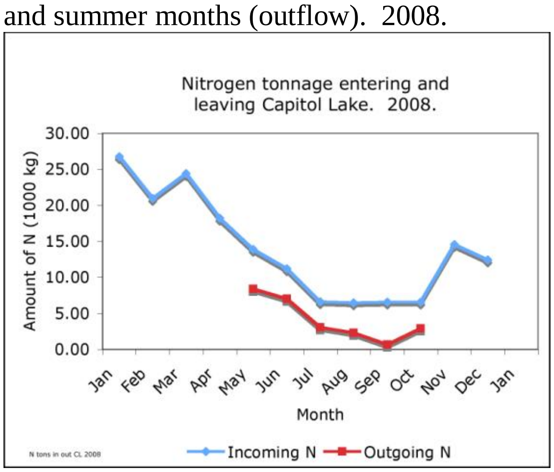


Figure 18. Amounts of nitrogen carried into Capitol Lake each month and carried out during months of the marine growing season. 2008.

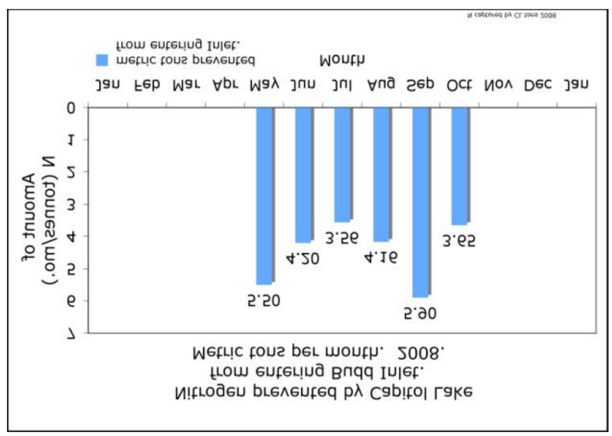


Figure 19. Metric tons of N nutrients prevented from entering Budd Inlet by Capitol Lake during the marine growing season, 2008. [These numbers are underestimates of the Lake's powerful effect; see Footnote 4.]

Starting on June 1, pour 60 bags of fertilizer into the water going over the dam into Budd Inlet every day for the entire month, to get an idea of how much nitrogen Capitol Lake keeps out of the Inlet during a month in the marine growing season.

The Lake reduces the tonnage of nitrogen nutrients entering Budd Inlet every month of the growing season.[xxii] That has been known since at least 1978, when the CH2M-Hill consulting firm reported this phenomenon to Washington's Department of Ecology. The Lake performs a free "ecosystem service" that is about the equivalent of passing the Deschutes River through two consecutive wastewater treatment plants, each with the nitrogen-removal capacity of our community's LOTT plant.[xxiii]

Without the Lake, all of the Deschutes River's nitrate would go directly into Puget Sound.

Did the BI Model Simulate The Lake's N-Reduction Accurately?

Did the Budd Inlet model successfully simulate the reduction of nitrogen nutrients going into the Inlet from the Lake?

Nowhere does the L/E Chapter in the TMDL Report mention this, and queries to the report writers by some interested parties have gone unanswered.[xxiv] I infer that the model does accurately simulate the Lake's N reduction, based upon data reported in the TMDL Appendices.

The model used for Capitol Lake's connection with Budd Inlet appears to be a combination of four models that team up to simulate the Lake system. These are (roughly) 1) a water movement ("Transport") calculator, 2) a model ("WQCBM") that mostly calculates water chemistry and water quality changes, 3) a model ("GAM") that calculates phytoplankton growth and its effects, all linked to a fourth model ("WQADD") that simulates the growth of macrophyte plants.[xxv] For some unexplained reason, the Lake is divided up for simulation into some 281grid squares, more than those for all of the much larger Budd Inlet (assigned 168 squares). About 10 depth layers are used, despite the Lake's shallow depths (average about 9 feet) and homogenous water columns.[xxvi]

The Lake model was calibrated by adjusting its parameters to make its output best fit observed data taken in 2004.

Figure 20 shows how the model's calculations matched DO levels observed at the Lake's surface during the calibration period. The computer's calculations tracked observed trends with reasonable fidelity. During that time DO remained at high concentrations seldom seen in salt water, all summer long.[xxvii]

The models were also used to predict dissolved inorganic nitrogen (DIN) levels in Capitol Lake during the calibration runs. Figure 21 shows its calculations for water at three sites – CL1, CL3 and CL4 – from May through September at the north ends of the South, Middle, and North Basins, respectively.

The graphs in Figure 21 show the model's prediction that DIN levels at all three sites will be about as high as is typical for Deschutes River water in early May. In this it is far off target for the Middle and North Basins, where the measured values (which show the Lake's N-removal process already in action at this early date) are less than half of the calculated predictions. By August the computer accurately reproduces what the Lake is actually doing, predicting DIN's near or at zero during mid-summer and matching the measured values.

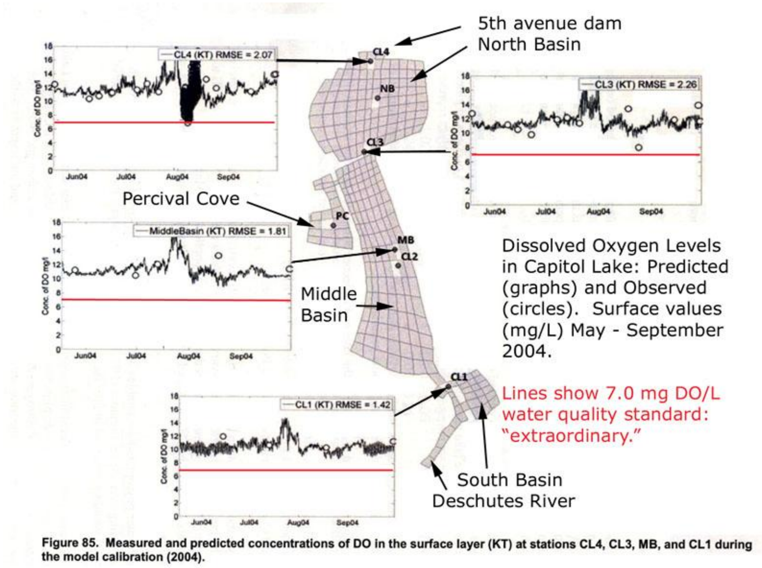


Figure 20. Grid used by Capitol Lake model, with summer dissolved oxygen levels at the surface calculated for four sample sites. Circles show surface values observed during that time. Figure 85, TMDL Report, with illustrative labels added.

My inference from these data is that, if this performance by the model as calibrated was achieved in the simulation runs, then the model accurately mimicked Capitol Lake's reduction of DIN in the discharge water.

What about the opposite case? Did the computer use elevated DIN levels characteristic of the Deschutes River in its Estuary Scenarios? No explicit mention is made of this in the TMDL Report.

We do have one strong indication that the Estuary Scenarios used nitrogen nutrient inputs that are higher than those used in the Lake Scenarios.
That is, the data in Figure 8 (analyzed earlier) could hardly have been obtained by this particular Model were it not comparing a low DIN Lake Scenario with a high DIN Estuary Scenario.

Capitol Lake's nitrogen removal capability is the Deschutes River Watershed's biggest water quality asset – something strangely missing from the TMDL Report. The data in Figure 19 (and the CH2M-Hill Report) should be foremost elements in any discussion of the Lake/ Estuary alternatives for the head of Budd Inlet.

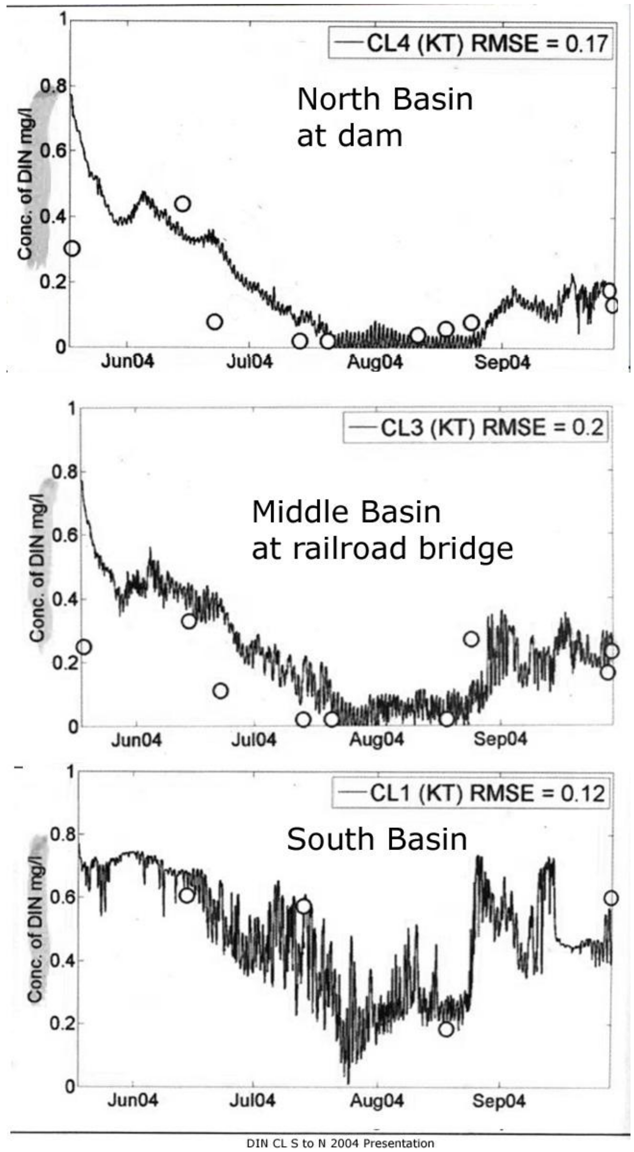


Figure 21. Comparison of the Lake Model's predictions (graphs) with measured values (circles) of dissolved inorganic nitrogen (DIN) at three Capitol Lake sites. May–September 2004.

Notes -- Section 7.

xviii The data used for this example were provided by John DeMeyer. He obtained them from two online sources provided by DOE. The Lake inflows and nitrogen concentrations can be seen at <_____>. The outflows and their nitrogen concentrations were posted on line in response to a request by JD but were removed after two weeks. He and I have not been able to relocate their source.

The data recorded by JD span 2004-2009. Inflow data are provided for every year. Outflow data were for the whole year 2004 and for the summer months only in 2005-2009, as seen in Figures 17 and 18 above.

I have used these "JD" data for this example for two reasons. 1) the nutrient levels reported are near those of the present time. 2) The outflow data were measured right at the dam. The earlier data reported by

CH2M-Hill (1978) show exactly the same pattern of nitrogen removal by the Lake and could have been used in place of the JD data. Advantages would be the certainty of the data source and a level of detail that allows us to identify the Middle Basin as the main site of nitrogen capture. Disadvantages would be that the CH2M-Hill data are decades old, we would need to infer that the nutrient concentration of the outflow is the same as that of the North Basin, and would need to infer that the outflow equals the inflow -- reasonable inferences, but not quite the same thing as certainty. In any event, the CH2M-Hill data show exactly the same pattern of seasonal nitrogen removal as do the JD data.

[xix] The "JD" data for 2008 included inflow from the Deschutes River for every month except September. (That datum is missing.) I have interpolated between the August (97 cfs) and October (102 cfs) inflows to estimate the September inflow at 100 cfs. That is the only datum that I have had to estimate for this data set. An alternative would be to assume the September inflow was the same as the September outflow (94 cfs). The two figures are so similar that I have used the interpolation for September inflow.

[xx] The Deschutes River comes close to being the largest contributor of nitrogen nutrients to all of South Puget Sound during the summer months. Of 56 South Sound large and small watersheds measured in 2006-07, the Deschutes River had higher nitrogen nutrient concentrations (about 0.8 mg NO_3+NO_2 per Liter) in its waters than all but 10 tiny inconsequential streams. On the same scale, the much larger Nisqually River was almost the lowest on the list (50^{th} out of 56^{th} at about 0.3 mg/L; see Figure F-2 p. 124, Mohamedali & other authors 2011). When the flow volumes of the waterways are considered, the discharges of the Nisqually and Deschutes Rivers are at the top of the list with nitrogen discharges at 1011 and 729 kg N/day (respectively Nisqually and Deschutes Rivers, 2007 annual monthly averages) and 199 and 198 kg N/day (respectively Nisqually and Deschutes Rivers, September 2007 averages). No other creeks are close to these numbers; the next largest September nitrogen discharge of 26 waterways listed by Mohamedali & others 2011, Table 7 p. 28, is from Chambers Creek at 112 kg N/day).

[xxi] The amount of nutrients entering the Lake omits the Percival Creek contribution. Including this omission would make the total "inflow" higher in nutrients, the "outflow" volumes and nitrogen concentrations the same, and therefore the removal ability of Capitol Lake even more impressive than the tonnages shown in these data.

[xxii] This is a true statement about dissolved nutrient nitrogen, but also only a partial representation of what is probably the whole nitrogen-budget situation. After the growing season, the lake plants die back and some of their foliage, stems, etc. begin to break loose and go over the dam. As these plant parts decay in salt water, the nitrogen they took up during the growing season is released. By this time phytoplankton growth has slowed dramatically and most of the released nutrients leave Budd Inlet, ultimately to reach the Pacific Ocean. The net effect of the Lake is to capture and hold a lot of nitrogen during the growing season, then gradually release much of it in the form of dead plant biomass to the Inlet after the growing season. (This is my expectation; I know of no studies that show this for Capitol Lake. Some such study is needed and would help determine an optimal lake vegetation harvest for maximizing year-round nitrogen removal by the Lake.)

[xxiii] … "Two LOTT plants = one Capitol Lake …" 1) From the JD data for September 2007; River inflow = 76 cfs with N concentration in inflow = 1.050 mg/L; outflow at dam = 79 cfs with N concentration in outflow = 0.282 mg/L; the Lake received 195.3 kg N/day incoming nitrogen and reduced it to 54.5 kg N/day outgoing before discharging it to Budd Inlet. 2) From Table 9 p. 36 Mohamedali & other authors 2011, the LOTT plant discharged 142 kg N/day as an annual monthly average in 2007 and lowered that to 76 kg N/day during September 2007 by "turning on" its nitrogen recovery apparatus. About 53% of the incoming nitrogen to the plant is still present in the outflow. 3) To reduce the ~195 kg/day incoming from the Deschutes River to the level discharged by Capitol Lake (~55 kg/day), the first LOTT plant treating the whole Deschutes River would reduce its nitrogen input to 53% of 195 or about 103. The second LOTT plant would reduce that level to 53% of 103 or about 55 kg N/day.

[xxiv] John DeMeyer and Bob Holman have inquired about whether the low N discharge of the Lake has been recognized and/or successfully replicated by the modelers.

[xxv] See pp. 187-189, TMDL Report. One infers from this reading that this combination of models is also the one that is used to simulate Budd Inlet with, of course, modifications to accommodate presence or absence of tides, salinity, and other properties of fresh- or saltwater systems.

[xxvi] My count of 168 grid squares used to simulate Budd Inlet is from Figure 84, TMDL Report. Figure 85 of the Capitol Lake grid shows 281 grid squares. Slightly different grid square numbers are occasionally mentioned in the TMDL Report (for example, 159 for Budd Inlet on p. ___), however the exact number doesn't matter. On page 18, TMDL Appendix H, statements are made to the effect that the shallow depth of the Lake and absence of stratification of its waters (that is, the water is homogeneous from surface to bottom) are such that simulation by layers is hardly necessary; the whole water column is the unit of interest.

[xxvii] Fresh water is inherently capable of holding more dissolved oxygen than salt water. At Tumwater Falls, the churning river water takes up oxygen from the atmosphere and is "100% saturated" when it enters the Lake just downstream. When the river is colder than the Lake, its entry flow can be expected to creep along the bottom – thus, by contrast with the situation in estuaries, delivering high-oxygen water to the bottom. This process usually keeps the DO of the bottom water near or at the same levels as prevail near the surface.

Section 8. Why do WQ standards violations keep showing up in East Bay?

Figure 22 shows a scenario pattern that occurs throughout the TMDL L/E Chapter. As in all other scenario findings presented in Format 1, the "violations" blamed on Capitol Lake are in East Bay or near its entrance. Might factors other than Capitol Lake be responsible for this pattern of "violations?" The answer is "yes," as explored in the following.

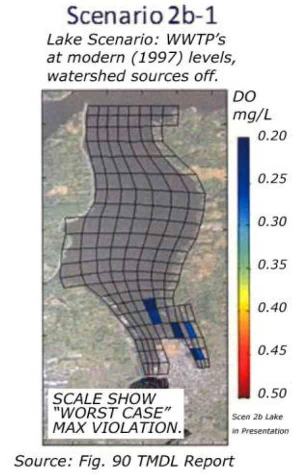


Figure 22. Lake scenario with watershed sources at "natural" levels and Waste Water Treatment Plants discharging at modern (1997) levels.

East Bay is far enough and physically isolated enough from the Lake water entering Budd Inlet at the dam that it may respond more dramatically to local inputs at the head of that bay than to the big inputs farther away. The small seldom-mentioned Moxlie Creek enters East Bay from a culvert. Its water typically has a high nitrogen concentration (about 60% of the median level in the Deschutes River in 2006-2007).[xxviii] This tiny creek dumped the equivalent of five or six 50-lb bags of fertilizer (of 10% nitrate content) into East Bay every day during September, 2007.[xxix] Because the Creek's flow is so small, it is unlikely that it sets up a meaningful estuarine circulation pattern like that which dominates West Bay. The mouth of East Bay is weakly blocked by a small fresh water outflow from Mission Creek (itself high in nitrogen nutrients) and a diffuse curtain of fresh water from the LOTT outfall between East and West Bays. All of this adds up to a semi-isolated, nutrient-stoked pocket of water whose main exchange with the rest of the Inlet is a non-directional back-and-forth tidal sloshing.[xxx] It is possible and even likely that the effects of this small creek dominate the computer's nearby grid squares more than do large inputs originating at the distant 5th Avenue dam.

It would be easy to find out. Simply set Moxlie Creek's nitrogen content at zero (not its "natural" level) and run a simulation again. (Evidently the Budd Inlet model is incapable of making such a simulation, but the Whole-Sound C/SPS DO Model can do it.[xxxi])

Notes -- Section 8.

[xxviii] Median N concentrations of 56 rivers, creeks and streams (including Moxlie Creek) are shown for 2006-2007 in Figure F2 p. 124 (Mohamedali & other authors, 2011).

[xxix] Table 7 (Mohamedali & other authors, 20ll p. 28) reports Moxlie Creek's daily discharge for September 2007 as 55 kg N/day.

[xxx] Further factors that isolate East Bay are the obstruction of surface flow by a dock that blocks about half of its entrance and the prevention of oxygen exchange with the air by boat hulls that cover 8-15% of the inlet. These factors are not included in the model but may contribute to the vulnerability of the Bay to real-life WQ standards violations.

[xxxi] A. Kolosseus, pers. Comm.. March 5, 2014.

Section 9. Was the Budd Inlet Model used "The Wrong Way?"

Deep in the heart of this whole vast complex simulation business is a critical first step that starts the procedure and governs the way in which all subsequent WQ standards violations are assigned. This section describes that first step, as best as possible from the sketchy information available. It appears that it was applied "The Right Way" for the Estuary Scenarios, but "The Wrong Way" for the Lake Scenarios.

The starting steps require that "Scenario 1" be created -- one version for the set of Estuary simulations and a second version for the set of Lake simulations. Scenario 1 is a preliminary run of the computer simulation for the water bodies in their "natural" pre-modern conditions with no inputs from WWTP's and no inputs of silt, nutrients, etc. from watersheds affected by such activities as logging, agriculture, and urban development.[xxxii]

When the Scenario 1 run is made with "natural" (pre-modern) conditions, every cell under every grid square is "watched" by the computer to see if the natural water ever, even just once for just six minutes throughout the entire computer "year" (January 15 – September 15), violates the modern 20th century water quality standards that have been assigned to those water bodies. At the end of the run, some squares are flagged for violations and all of the rest are unflagged.[xxxiii] *The calculations from all later simulations exploring this or that impact caused by modern human activities are compared with this Scenario 1 "grid map," cell by cell, moment by moment, area by area, all "year" long to determine where violations caused by those activities occur.*

To illustrate, Figure 23 shows a "Scenario 1 grid map" for Budd Inlet with Capitol Lake in place as calculated by the Model for all of Puget Sound (the C/SPS DO Model). It shows that with Budd Inlet and an imaginary Capitol Lake at a time when no modern human activities impacted the water quality, 20th century "standards" (= 6 mg DO /L outer Budd Inlet, 5 mg/L inner Inlet) would have been "violated" in the grey zone on the map and the respective standards would never have been violated in the red and green zones.

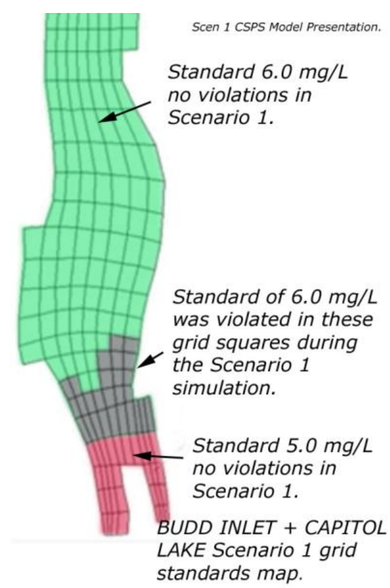


Figure 23. Scenario 1 grid map for Budd Inlet created by the C/SPS DO Model research team. I have added the red and green colors and labels. Source: Compiled from parts of Figure 45 SPSS Draft, p. 87.

In all subsequent simulations with Capitol Lake in place – "Lake Scenarios" that is – some with modern watershed impacts, some with WWTP impacts, some with both, DO's in cells in the green (or red) zones must fall below 6.0 (or 5.0) mg DO/L to flag a violation. In the grey zone, DO's must fall below either the natural DO level or the standard (in this case 6 mg/L), whichever is the lowest at that moment, to flag a violation.[xxxiv]

It appears that the Scenario 1 grid map was done "The Right Way" for the Estuary simulations. [*However, see End Note 4 below.*] That is, an estuary was envisioned "attached" to the south end of Budd Inlet, the estuary + Budd Inlet system were given pre-modern ("natural") levels of nutrient inputs, and then a "year"-long simulation was run comparing the "natural" water with 20th century water quality standards. From this comparison, an Estuary Scenario 1 grid map appears to have been created. <u>All later estuary simulations using modern levels of nutrient inputs were then compared with that grid map to identify areas in modern-day violation.</u>

The "Lake + Budd Inlet" Scenario 1 grid map was devised in a fundamentally different way. No modern numeric DO standards were assigned to the Lake. A Lake + Budd Inlet simulation using "natural" levels of nutrient inputs and other properties should have been compared with 20th century WQ standards to create a Lake Scenario 1 "standards grid map" for finding violations in later simulations using modern nutrient input levels.[xxxv]

Evidently there are no numerical standards for fresh water lakes; the "standard" in this case is the "moving target" of whatever the DO was in the "natural" water body less 0.20 mg DO/L

Figure 24 shows what happens when "modern" Capitol Lake is compared with "natural" Capitol Lake by this criterion. That comparison shows modern Capitol Lake in massive violation of water quality standards in every grid square. The reason is that in "modern" times, the Deschutes River is thought to be 3^{o}C warmer than in its "natural" condition, reducing the water's ability to hold oxygen even when saturated by passage over the falls. A warmer modern River and Lake guarantees that "violations" will be "found" everywhere, less so in the Lake (where plant photosynthesis makes up some of the difference) than in the free-flowing river.

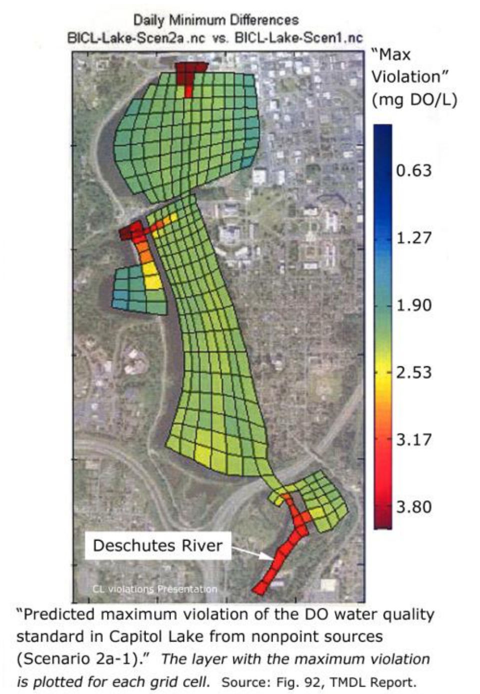


Figure 24. Purported violations of (never specified) water quality standards in Capitol Lake compared with some (never-specified) "Lake Scenario 1" with Deschutes River and Percival Creek nutrient inputs at modern levels.[xxxvi] Source: TMDL Fig. 92 p. 208.

The bottom line is that the procedure used flags the 1997 lake water for "violations" everywhere, despite the fact that it has modern DO's higher than 7.0 mg DO/L – often higher than 10 -- throughout the year, often from top to bottom (see Figure 20 above). The TMDL Report rationalizes that, no matter what the high level of DO in Capitol Lake may be under modern conditions, any decline of 0.2 mg/L or more below *the "natural" conditions qualifies as a "violation." (p. 203, TMDL). What would be "extraordinary" water quality in Budd Inlet is therefore shown as a "violation of water quality standards" in Capitol Lake.*

For salt water, 20th century numeric standards are assigned at the outset and the water in its pre-modern "natural" (Scenario 1) state is compared with those standards throughout a computer "year." As shown by Figure 23, the DO in every cell under most of the grid squares in "natural" Budd Inlet <u>never</u> *violated the modern standards, even for 10 minutes of the "year." Nothing is said in the TMDL Report about the standard that the Estuary (Scenario 1) water was compared with, but the impression gained is that, like East and West Bays in Figure 23, whatever the chosen standard was, it was never violated. The "playing field wasn't level;" the salt water in the basin, undoubtedly with lower DO's than the fresh water in the basin, was given a much less stringent standard to measure up to than was the fresh water.*

The biggest gap in the TMDL Report L/E Chapter is its omission of descriptions of the Lake Scenario 1 and the standards applied to it, and the same information for the Estuary Scenario 1. If there is a future edition of that Report, this major deficiency needs to be remedied.

When Budd Inlet was simulated as part of the large Central/South Sound study, the model used (C/SPS DO Model) definitely included the fact that Capitol Lake reduces the nitrogen nutrient load that would otherwise be discharged to Puget Sound by the Deschutes River. Since that model has fewer grid squares than does the Budd Inlet Model, it also simulated the discharge of the Capitol Lake outflow to the whole south end of West Bay. (In the Budd Inlet Model Scenarios, the Estuary discharges to the whole south end of West Bay whereas the Lake discharges to just one grid square – a structural model artifact that could account for differences in Lake/ Estuary outcomes.) In this case the modelers probably used the same data from "natural" pre-modern times for the river and lake as were used by the Budd Inlet modelers.

When this large-scale Sound-wide simulation engine was run with these differences from the Budd Inlet Model simulations …

… it showed no net difference between the Lake and Estuary outcomes.

As did the BI Model, the C/SPS DO Model mapped out regions of mostly feeble WQ standards violations. With the Lake present (the only case that this model is set to simulate) these violations are, as usual, mostly in or outside the mouth of East Bay (Figure 25, left). An "Estuary" case borrowed from the TMDL research is compared with it (Figure 25 right). The Estuary case shows the usual East Bay flagged violations, tiny WQ standards violations extending to the west shore of Budd Inlet, and a few more seriously affected cells right in West bay itself. [xxxvii]

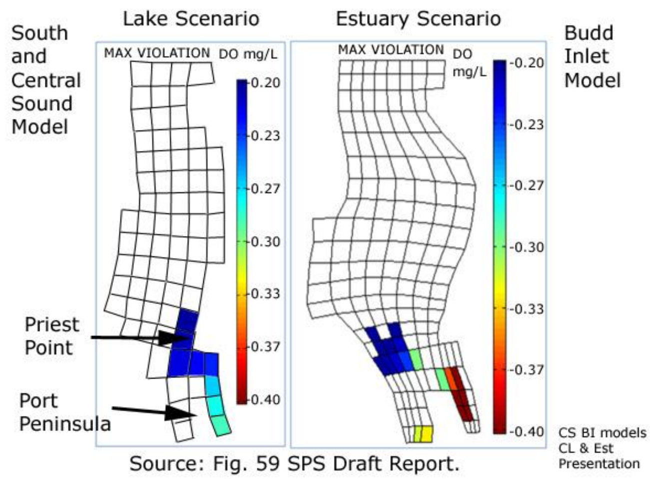


Figure 25. Output of the S/CS DO Model with Capitol Lake included (left) and the BI Model with Capitol Lake replaced by an estuary (right), for Budd Inlet.

As pointed out in Sections 2, 3, and 4 above, it is a mistake to use flagged patches of miniscule WQ standards violations as a way of blaming Capitol Lake for problems in Budd Inlet. It is also a mistake to assume that every flagged patch is traceable back to the Lake and not, say, to a local source like Moxlie Creek or to a model artifact like the difference in grid squares receiving discharges between the Lake and Estuary simulations. The C/SPS DO Model seems to have shown us that standards violations are still to be found when sought by a more powerful, versatile model, but that they do not seem to be much different between Lake and Estuary scenarios.

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[xxxii] The amounts of nutrients discharged to Puget Sound by rivers and creeks in former pre-industrial times are not zero. Estimating those amounts is a real challenge to modelers, ecologists, and others interested in understanding the natural landscape of the past. Usually there are few early era measurements to rely on, but from studies of modern creeks in "untouched" landscapes (and other research) values can be estimated with a fair level of confidence. These values are used in the Scenario 1 simulations.

[xxxiii] It is surprising how often "natural" conditions violate modern 20th-century WQ Standards assignments. In a C/SPS DO Model simulation of all of Puget Sound from Edmonds to Olympia as it probably existed in its natural state, fully 93% of the main body of Puget Sound violated the modern standards (see Figure 45 p. 87 SPS DO Draft.) This massive violation was made nearly inevitable by assigning a very high 20th century standard (7.0 mg DO/L) to most of Puget Sound from surface to bottom, despite that fact that the bottom water entering from the Pacific Ocean contains much less oxygen than this concentration most of the year. (Barnes & other authors, 1964.)

[xxxiv] This is the "moving target" mentioned in Section 1.

[xxxv] *Starting on page 32, the parts of this section that are written in italics were substituted for my original text as a result of new information provided by the TMDL modelers on March 20. The respondents (see*

"Ahmed and other authors, 2014" in the References section) explained the method by which they found water quality standards violations in Capitol Lake. (This clarified the interpretation of Figure 24, which, absent an explanation in the TMDL Report, I had inferred had been obtained by comparing the Lake with salt water.) It appears that a credible "Right Way" Capitol Lake Scenario 1 was constructed, but the Lake was then compared with a much different set of water quality standards than the ones used for the Estuary Scenario 1 waters.

Some doubt remains. Many of the same modelers ran the C/SPS DO model with a "Right Way" Capitol Lake Scenario 1. But the same modelers make this statement: "The Budd Inlet project has determined that the natural condition against which scenarios are compared is without the Capitol Lake dam." (p. 104 C/SPS DO Draft) – seemingly implying that both Lake and Estuary must use the Estuary Scenario 1. That is the only sentence of explanation available in the C/SPS Draft and the TMDL Report.

[xxxvii] The "Estuary Scenario" figure borrowed by the C/SPS researchers and shown in Figure 25 right above is most similar to a "Scenario 4" estuary figure on page 93, TMDL Report. "Scenario 4" is run with the LOTT plant discharging at the maximum level permitted (about four times its present-day discharge) and the Deschutes River at its modern level of nutrient discharge. The "Lake Scenario" figure calculated by the C/SPS researchers (Figure 25 left above) most closely resembles the "Scenario 4" lake figure on page 206, TMDL Report.

Section 10. REFERENCES.

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"SPS DO Draft." See Ahmed and others (2013) above.

"TMDL Report". See Roberts and others (2012), above.

TMDL Appendices. Same as Roberts and others (2012) above. Appendices A & B (Glossary and Acronyms/Abbreviations) included with the TMDL Report. Appendices C – M available on line only at the site shown for Roberts et al (2012).

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Conclusions and Recommendations.

As best I (the author) can tell from the TMDL Report findings, there is no indication that Capitol Lake has any negative effect on Budd Inlet's water quality. Indeed, it appears that the Lake's discharge water suppresses eutrophication of Budd Inlet – a major beneficial water quality impact.

The simulations described in the TMDL Report were directed at producing "patterns" – not at finding "underlying mechanisms" by which water from the Lake or Estuary might influence Budd Inlet. The patterns of water quality standards violations shown in Formats 1, 2, and 3 contain useful information but are easily misinterpreted and do not lend themselves to understanding the dynamics of the Inlet, Lake, or Estuary.

Where do we go from here? I recommend the following.

1) Describe in detail the "natural" Estuary Scenario 1 and Lake Scenario 1. *Give the numerical values* of all 20th-century water quality standards against which the "natural" water in each grid cell is initially compared when the respective Scenario 1's are tested against modern water quality standards; outer Budd Inlet, inner Budd Inlet, in the Estuary, and in the Lake. Show via a grid map (like Figure 45 in the South Puget Sound Dissolved Oxygen Study, copied in Figure 26 here) all grid cells in which the water of Inlet, Lake, and Estuary in its "natural" (= pre-modern) condition does or does not violate the standards.

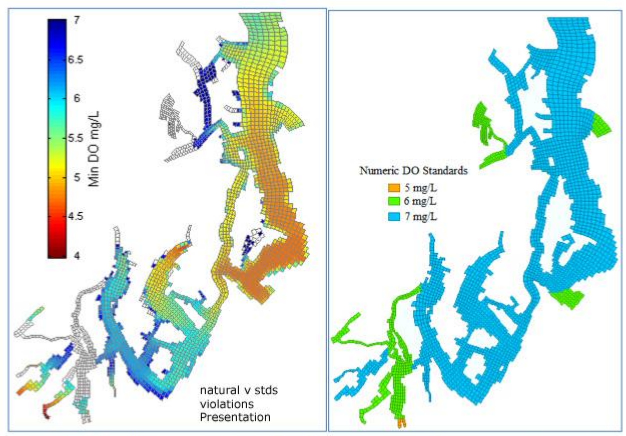

Figure 45. Grid cells with minimum DO below the numeric standard under natural conditions. Cells in white are above the numeric standards under natural conditions.

Figure 26. Water quality standards violations in Scenario 1 for Puget Sound (left) compared with 20th century water quality standards (right). This is Figure 45 of the C/SPS DO Draft Report; comparable maps should be shown for Budd Inlet, both for the Lake and for the Estuary Scenario 1's.

[*The results of this exercise will take the form of a map of Inlet + Estuary with the standards shown on the whole map, a map of Inlet + Lake with the standards shown on the whole map, and final separate grid maps for Inlet + Lake and Inlet + Estuary showing areas where the natural waters violate modern standards and areas where they do not (as in Figure 26). This exercise should show us whether the Lake /Estuary comparisons in the TMDL Report were made with a flawed Lake Scenario 1 formulation*.]

2) Determine whether it is plausible that Capitol Lake influences East Bay by running a season-long simulation with a "dye tracer" released at the 5th Avenue dam/estuary mouth, to see where the discharge water actually goes after it enters West Bay.

[*Data in the TMDL Appendix indicate that in July 1997, at least, water from the dam does not approach East Bay in any significant amounts. A season-long simulation can tell us whether that is also the case during the rest of the marine growing season*.]

3) Test the possibility that the patterns seen in and near East Bay are influenced by local sources such as Moxlie Creek and/or the LOTT outfall – not Capitol Lake or the Estuary by running the simulation with Moxlie Creek's nitrogen content set at zero with all other Lake and Estuary values set at their modern (watershed + WWTP) levels.

[*Not recommended here but perhaps consider for future simulations; include in the model the effects on DO of the raft of boats and docks blocking about half of the Bay's entrance (and covering about 10% of its surface area) on surface outflow and uptake of oxygen from the air in East Bay*.]

4) Obtain from stored data the dates upon which the "worst case DO differences" shown in TMDL Figure 87 (p. 200) occurred and the depths at which they occurred, and show the vertical profiles of DO concentrations in each depth layer under the labeled grid squares BI-1, -2, -4, -5, -6, BA-2, BB-2, BC-2, BD-2, BE-2, BF-3 (Appendix G p. 17).

[*If the vertical profiles show the Estuary creating more oxygen at or near the surface – in the "euphotic zone" – than does the Lake, then the Figure shows a beneficial impact of the Lake on Budd Inlet*.]

5) Clarify the interpretation of Figures showing the duration of WQ standards violations (Figures 91 and 94, TMDL pp. 207 & 210), particularly the interpretation of the scale "days/layers."

6) If it is deemed useful to continue using the existing model for the Lake/Estuary pattern comparisons (or if it is the easiest next step), run the Estuary simulations again for several additional years; a wet year, a dry year, and 2004, and compare the outcomes with the patterns of "Estuary" WQ standards violations obtained for 1997.

[*In general, a single simulation of a complex system influenced by phenomena that change yearly in ways that are partially random (as, weather patterns) or in ways that are completely predictable (as, tide patterns) is not enough for confidence that the system is well understood. Running it again for a recent "wet" year and a recent "dry" year would sharpen our focus on whether the results using data for 1997 are typical. Because the Budd Inlet model was calibrated with 1997 data, whereas the Lake and Estuary models were calibrated with 2004 data, a 2004 simulation ought to be included in any extra runs of the model. The 1997 model run for the Estuary scenarios was probably done "The Right Way;" comparing those runs with data from other years would probably be trustworthy*.]

7) If feasible, "broaden" the Capitol Lake outfall so that the discharge enters all four grid squares at the south end of West Bay (as in the Estuary Scenarios) and try future Lake Scenarios with that condition. If feasible, model the Lake and Estuary with grids whose squares are the same size as those used for Budd Inlet.

[*This addresses the possibility that artifacts of the model, rather than real-life differences between the Lake and Estuary systems, may play a role in the patterns of WQ standards violations shown in the L/E Chapter. The estuary is modeled with a 500-foot outflow (from the lower West Hill roundabout to Bayview Market) essentially emptying into the whole south end of West Bay*[xxxviii]*, whereas the narrow Lake outflow is confined to just one or two grid squares there. The Lake and Estuary models also use more grid squares for those small bodies of water than does the model for all of Budd Inlet. These differences between* <u>*models*</u> *could influence the final simulation results as much as (or more than) the differences between Lake and Estuary* <u>*systems*</u>.][xxxix]

8) Make a data CD showing Salinities, Temperatures, and DO's in each depth layer for each month (April – September) for the grid squares mentioned in (4) above available to parties who request it.

10) For future simulations, avoid Format I presentations of data. Show depths and dates of WQ standards violations and the durations of violations in consecutive minutes, days, weeks, or months in conventional formats.

11) If there is to be a future edition of the TMDL Report, include text and figures explaining the removal of nutrients from Deschutes River water by Capitol Lake.

[xxxviii] 500-foot opening; see p. 197, TMDL Report

[xxxix] The modelers themselves note that the South and Central Sound Model's fewer, larger grid squares won't "find" as many "violations" as can a model with more numerous, smaller squares. P. 104, South Puget Sound Dissolved Oxygen Study Draft.