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

7. CAPITOL LAKE: ERRORS AND MIS-CHARACTERIZATIONS.

Page 58 of the SM Report begins a short, error-filled section on Capitol Lake itself. A key image repeated three times in that section is reproduced here in Figure 7-1 below. (The original first appearance of this image was in 2012 in the TMDL Report, there shown as Figure 92.) Wherever this image appears in the SM Report, the caption refers to "oxygen depletion" in Capitol Lake. As I show in the following, there is *never* any meaningful, real-life oxygen depletion in Capitol Lake, and even the theoretical "depletions" shown in this image are grotesquely in error.

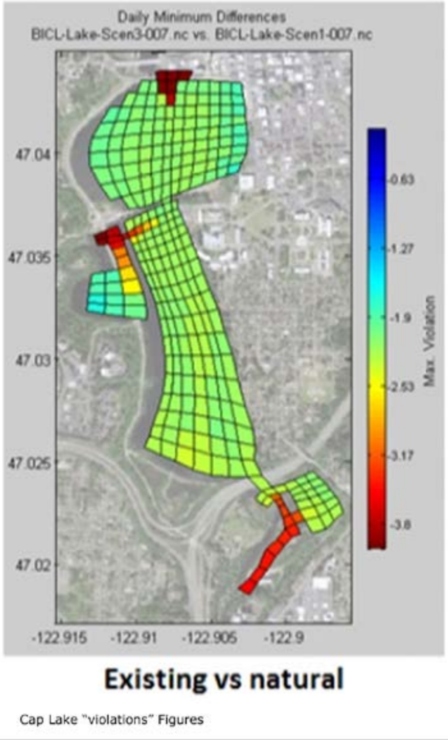

Figure 7-1. Output of the Ecology computer model that portrays all of Capitol Lake in significant "violation" of some dissolved oxygen water quality standard. Source: SM Report p. 60.

7-a. There is *No* "Oxygen Depletion" in Capitol Lake.

A few introductory words on how lakes (and marine waters) become oxygen-depleted are in order. The oxygen depletion story begins with the addition of excess nutrients (usually nitrogen and phosphorus) to the water. There they fuel the rampant growth of plants and phytoplankton, which eventually sink to the bottom and decay. The decay (by bacteria) uses up oxygen. If there is enough sunken plant material, its decay can use up virtually all of the oxygen in the bottom water. This process is well known to aquatic ecologists.

The result of this process is shown in Figure 7-2, which depicts a vertical DO profile in Hicks Lake in Thurston County. On June 20, 2011, the amount of oxygen in the water declined from a high level at the surface to zero at the bottom, almost certainly as the result of decay of sinking plant matter by the bacteria there.

Figure 7-3, constructed from all of the monthly vertical profiles presented in TCPHSS Report 2012, shows that Hicks Lake's bottom water was devoid of oxygen from June through October, 2011. Similar constructions for all of the lakes monitored by the Thurston County Health Department (Figure 7-4) show that *all* of the county's monitored lakes experience severe oxygen depletion at their bottoms … except one.

The exception is Capitol Lake. There, the North and Middle Basins *never* became fully or even partially DO-depleted at the bottom in 2011 (and in 2005, included to show that the data gaps for 2011 weren't hiding DO problems).

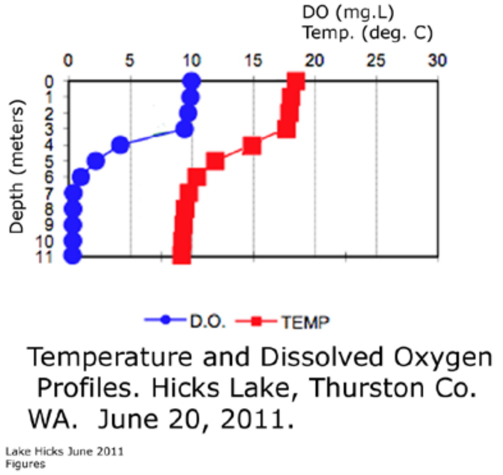

Figure 7-2. Change in dissolved oxygen and temperature with depth, Hicks Lake, Thurston County, June 20 2011. Source: Thurston County Water Resources Report 2012. (The TCPHSS original Figure has been simplified by removal of vertical profiles of pH and conductivity.)

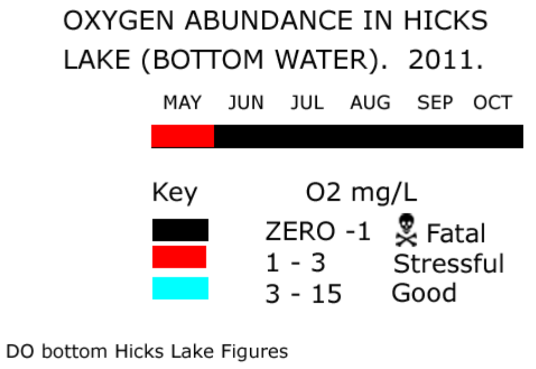

Figure 7-3. Dissolved oxygen in the bottom water of Hicks Lake, May – October 2011. Source: TCPHSS 2012.

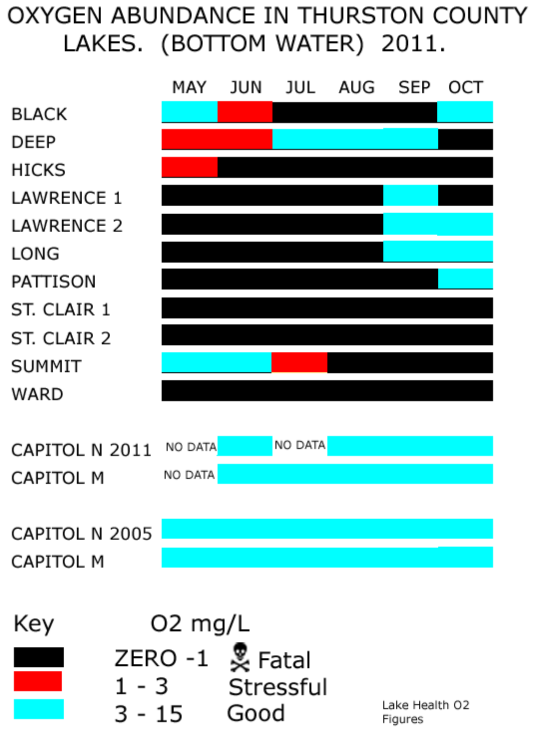

Figure 7-4. Seasonal bottom water DO concentrations in 10 monitored Lakes in Thurston County in 2011. Source: TCPHSS Report 2010-12.

Why is Capitol Lake the exception, despite the enormous load of nutrient nitrogen and phosphorus dumped into it daily by the Deschutes River? The River itself is the answer.

Unlike the other lakes, which are enclosed basins, Capitol Lake is a flow-through ecosystem that is constantly refreshed by the entry of river water at its southern end. The river water is supercharged with oxygen by its passage over Tumwater Falls. The result is that *the water entering Capitol Lake is always as high in dissolved oxygen as it can naturally get* (100% saturated) without the additional help of plant photosynthesis. *Always*. Because it is almost always cooler than the Lake water, the river flows along the bottom, slowly upwelling as it goes. The result is that the bottom water of Capitol Lake (and all of the rest of the water as well) *never* runs out of oxygen no matter how much decay of sunken plant matter takes place. In this regard Capitol Lake is an “oxygen superpower,” an “oxygen blast furnace,” unlike every other lake almost everywhere else and unlike the marine water just beyond the dam.

Figure 7-5 shows dissolved oxygen levels in the Middle Basin of Capitol Lake during the 2014 growing season. The Basin’s DO levels remain at values classified as “extraordinary” all season long, never dropping to the level of the standard for the lower Deschutes River (8.0 mg/L).

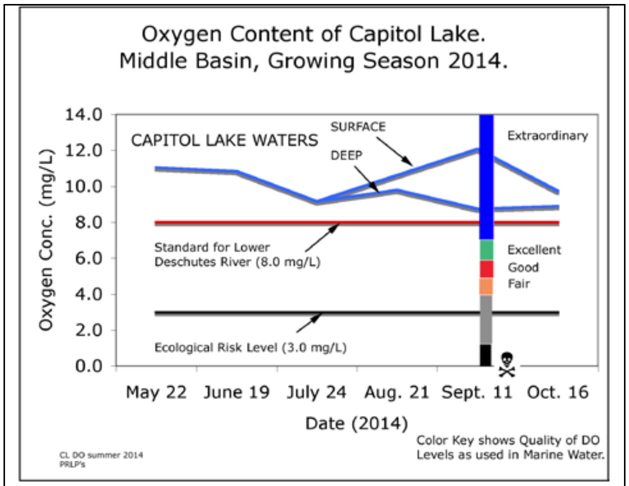

Figure 7-5. Real-world Capitol Lake dissolved oxygen levels, 2014. Measured DO levels of Capitol Lake (upper lines), May – October 2014, Middle Basin. Water quality standard for lower Deschutes River (8.0 mg/L) and low-DO ecological risk level (3.0 mg/L) are also shown. Water quality labels used to describe DO levels of various amounts are shown on colored scale. Sources: TCPHSS 2012-14; Ahmed et al 2013; Vaquer-Sunyer and Duarte 2000.

There is *never* a real-world problem with “oxygen depletion” in Capitol Lake. The modelers’ use of that term is misleading and should be discontinued. The term they should use is what they actually mean, that is “Theoretical Water Quality Standards Violations.”

7-b. Phosphorus Levels are Irrelevant in Capitol Lake.

The SM Report devotes considerable space to a discussion of phosphorus nutrients in Capitol Lake. While that is of interest, that is irrelevant. Phosphorus inputs to Capitol Lake are high, as they are in several other County Lakes.[1] This common affliction has little to do with Capitol Lake’s relationship with Budd Inlet.

Phosphorus nutrients, as do nitrogen nutrients, support plant growth in Capitol Lake. So much plant growth occurs there, in fact, that the Lake is classified as “Eutrophic.” The term has a negative connotation, mainly because eutrophic lakes often have the kinds of oxygen-depleted bottom waters that occur seasonally in most of our area lakes, other than Capitol Lake (as in Figure 7-4). That negative connotation is not applicable in this case. Nevertheless it is used by the modelers to brand Capitol Lake as somehow impaired. Two of the SM Report Figures (Figs. 37 and 38, not reproduced here) aim to show the seeming hopelessness of removing Capitol Lake from the “Eutrophic” category by dredging as a way of reducing phosphorus loading. That is probably true, but it is of no significance.

Phosphorus nutrients consist almost entirely of phosphate ions, PO_4^{3+}. Unlike the nitrogen nutrients, phosphate is removed from lake water by chemical combination with ele-

---

[1] Five local lakes (including Capitol Lake) are listed by the EPA as “Clean Water Act Category 5 impaired waters” requiring remedial attention to elevated phosphorus levels. (The other four are Long, Lawrence, Pattison and Black Lakes. Source: WDOE 303d List).

ments in the sediments (mainly iron). For as long as the bottom water is oxygenated, the phosphorus stays trapped in the sediments. For Capitol Lake, that is all year long. When more typical eutrophic lakes go anoxic at the bottom, the ferric compound that bonds the phosphate ($Fe_3(PO_4)_2$) becomes a ferrous compound and liberates the bound phosphate, which escapes back to the water column. The escaped phosphate eventually returns to the sediments later in the year, but before that happens some of it fuels the luxurious growth of plants and phytoplankton for which eutrophic lakes are noted. This is probably the case for the lakes listed in Figure 7-4 above – but not in Capitol Lake.

There is no discussion in the SM Report of how reducing nitrogen nutrient inputs would affect the lake and, by extension, Puget Sound. Unlike the situation in other eutrophic lakes, nitrogen – not phosphorus -- is the limiting nutrient in Capitol Lake (CH2M-Hill 1978; see also Figures 23 and 24, TMDL Report). Capitol Lake is one of the few area lakes that doesn't support a significant population of blue-green algae, the biotic creators of nitrogen nutrients that eradicate nitrogen shortages in those other lakes and make phosphorus the key to their rampant plant growth.

The myopic focus of the SM Report on the hopelessness of changing the eutrophic classification of the Capitol Lake (pp. 65 and 66) and the impossibility of changing its "oxygen concentrations" by changing its phosphorus budget (p. 68) is a tangential distraction that misses the point. Nitrogen is the key to the Lake's ecology and its powerful role as a protector of Puget Sound – phosphorus has little to do with it.

7-c. Dissolved Oxygen "Deficiencies" in Capitol Lake Were Calculated Incorrectly.

1) Background for the *Correct* Calculation.

Repeated mention is made of "DO depletion" in Capitol Lake throughout the "Capitol Lake Scenarios" section of the SM Report. In real life, the oxygen levels in the Lake are always at the "extraordinary" highest level of classification (Figure 7-5). What DO standards could possibly be violated in a Lake that is always extraordinarily high in dissolved oxygen? The answer is that the "DO depletions" (violations) are not in the real world; they exist only in the same Violations Happy Hunting Ground that we encountered in Section 2 -- the computer "cyber space" that simulates the "natural conditions" of a water body and then compares them with its simulated modern conditions.

The "violations" obtained by the Model from the "natural" water comparison are gigantic – fully 4 mg/L in the parts of the Lake closest to the Deschutes River, Percival Creek, and the dam (red zones, Figure 7-1). How does this relate to the Lake that we know? Some explanations and reminders are in order here.

Lakes do not have set numerical water quality standards (TMDL Report, pp. 19-20). Instead, the method used to determine whether a lake's waters are degraded is to compare its condition in modern times with its condition in some pre-modern era when it was "natural" and to declare a WQ Standards Violation if the modern water is 0.2 mg/L (or more) below that bygone "natural DO level." As always, the challenge is to determine what the “natural” DO levels were in the Lake before the modern era. There is a difficulty here in that the Lake didn’t exist in pre-modern times, but it is easy to envision one such impoundment formed by natural causes (say, water dammed by a rock barrier as seen in some coastal British Columbia estuaries) and proceed from there.

There is a second difficulty, namely; “Should the ‘natural’ Capitol Lake be considered a lake, or simply a slow-moving part of the ‘natural’ Deschutes River?” If it were considered a slow-moving river, the standard for the lower Deschutes River (8.0 mg/L) would be used and the ‘natural’ lake DO would need to drop below that value before its DO content could be used for finding “violations.” It never does that. That would be the end of the computer modeling story.

A dammed reservoir can be defined as a “lake,” however, in this way (used by the modelers). Divide the reservoir’s volume by the lowest average 30-day river flow of the past 10 years and if the answer (= residence time of the water in the basin) is greater than 15.0 days, the dammed reservoir is considered a “lake,” not a slow-moving “river.” The modelers did so, using a low flow value apparently obtained by word of mouth,[2] and found that the residence time of water in the lake at this low flow rate is 15.2 days – just long enough to qualify as a “lake.”[3]

With that definition the 8.0 mg/L DO standard for rivers goes out the window and the modelers are free to use the ‘natural’ DO levels in the Lake as the moving, changing, unknowable standard against which modern levels can be compared. Since there are no modern standards for lakes, any modern DO levels that are lower than their calculated counterpart ‘natural’ levels in Capitol Lake by 0.2 mg/L or more result in “violation” labels for their locations in the Lake. Since lakes don’t have fixed modern standards, this opens the gates to the Violations Happy Hunting Ground for the whole lake, every location, every moment, every depth. Figure 7-1 above, showing every location in this high-oxygen Lake plastered with large “violations,” is the result of that process.

When I first saw this Figure in the TMDL Report, I found it so contrary to expectation and common sense that I wondered whether it really showed something else; namely how much more oxygen would be present in the Lake water than in an estuary’s water if the estuary replaced the Lake. I asked the modelers how they obtained such results. Their answer (long delayed) was that they considered the ‘natural’ Deschutes River to be 3^{o} C colder than the modern river, thanks to global warming. Since cold water holds more oxygen than warm water, the violations shown resulted from that initial condition.[4]

---

[2] They cite “D. Kresch, personal communication 2003”, p. 13 TMDL Report, not cited in their references.

[3] In doing so, the modelers are simply following legal guidelines for defining lakes and for examining best-guess ‘natural’ conditions to advise on modern water quality. I have used this “flow through” procedure to calculate low-flow residence times and find that, in some summer months of some years, the residence times can be as high as 20 days. Orsborn and others (1975) show that such residence times should be expected only once in every 47 years – a complication that suggests that this frequently-recurring modern condition is only tentatively comparable with typical past ‘natural’ conditions (Orsborn and others, p. 45).

[4] [Due a formatting difficulty this footnote is on the following page.]

An important drawback of using ‘natural’ conditions to find DO “depletions” in modern water is that it is almost always impossible for some third party to check up on the calculated findings. To do so one would need to know all of the ‘natural’ DO’s calculated by the computer for every depth, every location, every 6 minutes, from January 25 to September 15, then all of the same values as calculated for modern waters. The Capitol Lake case provides a rare exception. Here, for some of the grid cells, we can “know” what the natural values must have been, assuming that the river was 3^{o} C colder in the past.

The exceptional circumstance that makes a checkup possible is that the water entering the south end of Capitol Lake must always be 100% saturated with oxygen, from its passage over Tumwater Falls. Whether the water was more or less saturated when it started over the Falls, that churning tumbling exposure to the atmosphere will always “re-set” it to 100%. That knowledge enables us to calculate the ‘natural’ DO levels at the south end of the Lake (the “red zone,” Figure 7-1) back when the river is said to have been 3^{o}C cooler and compare them with the modelers’ grotesquely mistaken findings.

2) Methods. Checking The Dissolved Oxygen Calculation.

Figure 7-6 is a “nomograph” that was used in the pre-computer era for fresh-water dissolved oxygen calculations. It is a diagram with three carefully arranged scales that show the following (top to bottom); (1) water temperature; (2) per cent DO saturation of the water; and (3) DO level in mg/L. If you know any two of those quantities, you can use the nomograph to find the value of the third.

The nomograph is used by placing a straight-edge (ruler) on the diagram aligned so that it crosses two of the scales at the known values, then finding the third value by seeing where the straight edge crosses the third scale. For example, if you know that the water temperature is, say, 8.64^{o}C and its per cent saturation with oxygen is 100%, a ruler placed at these values on the upper two scales crosses the lower (DO) scale at 11.35 mg/L. That is the amount of oxygen that fresh water will acquire via contact with the atmosphere if its temperature is 8.64^{o}C to become 100% saturated.

[note 4 p. 7-5] The full text of the modelers’ answer to my question is as follows: “The other change reflected in the model is the Deschutes River temperature that would occur under natural conditions. We consulted the river projections for temperature, which would be over 3^{o}C cooler under natural conditions. Cooler water holds more oxygen at saturation, so the river would also have higher oxygen concentrations. The differences between natural and existing oxygen concentrations predicted in the south basin of Capitol Lake mostly reflect the river temperature and dissolved oxygen differences. This effect is limited to the south basin, however (red cells in [TMDL’s] Figure 92). Oxygen levels in the middle and north basins reflect productivity within the lake.” (Ahmed et al, 2014).)

I used the nomograph to calculate the sizes of the "violations" of DO standards for five dates in the river's 'natural' past. Table 7-1 illustrates the procedure and the values obtained.

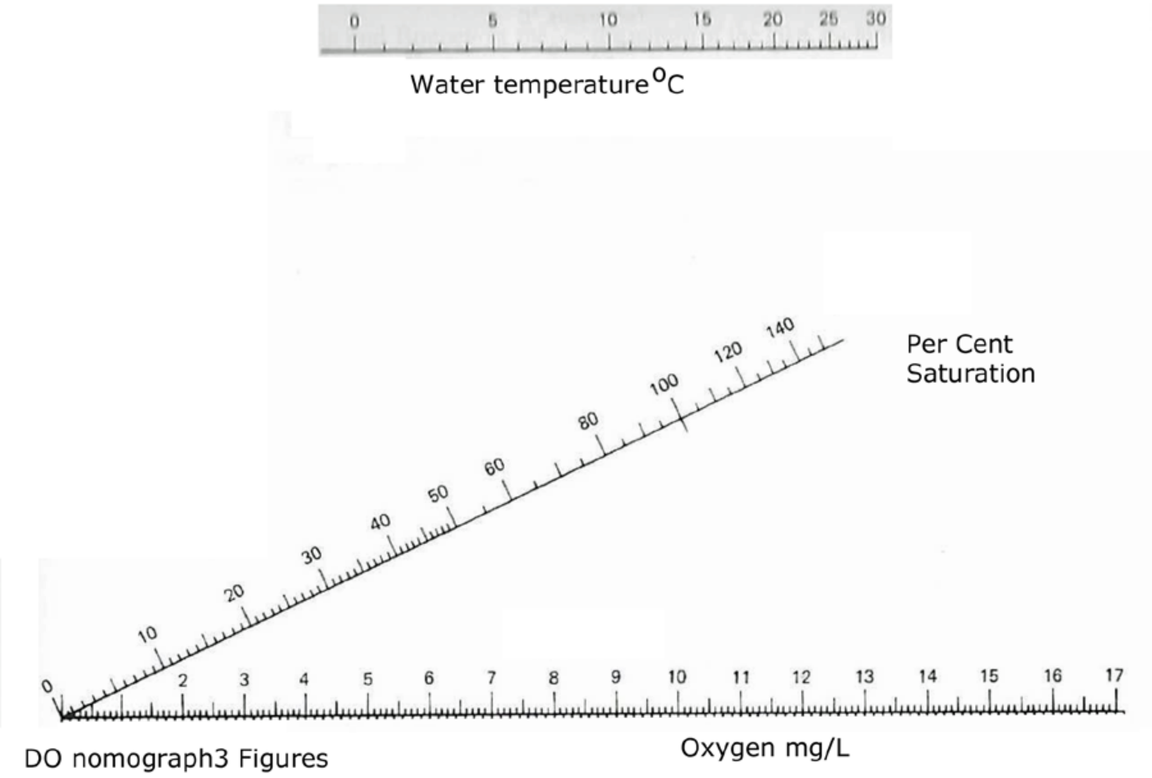

Figure 7-6. Nomograph for determining the amount of dissolved oxygen in fresh water at full (100%) saturation, using the temperature of the water (at sea level atmospheric pressure). Full (100%) saturation is the amount that the water acquires via contact with the atmosphere with no additions from plant photosynthesis or subtractions via respiration or chemical contamination. Source: Horne and Goldman, 1994. The original nomograph's corrections for lakes at high altitude are not shown.

The calculation begins with observed modern water temperatures and DO's for the River water as measured in Tumwater Falls Park, a location below the Falls that is marginally the southernmost part of Capitol Lake (2010 data, TCPHSS 2012, Columns A, B and C, Table 7-1). I used the nomograph to confirm that these modern values are at or near 100% saturation (Column D). Column E shows the 'natural' temperatures that the modelers would assign to the pre-modern era, namely temperatures 3^{o}C lower than those in Column B. Column F shows the dissolved oxygen levels that would have been present if the water were 100% saturated with oxygen at the 'natural' temperatures. Because of the colder 'natural' water, these levels are higher than the modern levels. The differences are shown in Column G. A "violation" is declared if that difference is greater than 0.2 mg/L. The amount of difference in excess of 0.2 mg/L – that is, the size of the 'violation' – is shown in Column H.

A	B	C	D	E	F	G	H	
				Temp-3	100% sat	difference	"violations"	
Date	Temp	DO	% sat.	=B-3	DO @T-3		G-0.2	
(2010)	(^{o}C)	(mg/L)		(^{o}C)	(mg/L)	(mg/L)	(mg/L)	
Apr 19	11.64	10.24	98	8.64	11.35	1.11	0.91	
May 10	11.64	10.18	97	8.64	11.35	1.17	0.97	
Jun 15	11.92	10.37	99	8.92	11.20	0.83	0.63	
Jul 12	15.83	ND	-	-	-	-	-	
Aug 16	16.58	9.31	98	13.58	10.05	0.74	0.54	
Sep 13	13.27	9.52	95	10.27	10.40	0.88	0.68	

Table 7-1. Calculation of the DO levels that would exist in the Deschutes River and southernmost Capitol Lake if the 'natural' River were 3^{o}C cooler than at present. Columns A, B and C; dates and observed data for Tumwater Falls Park, 2010. (Source: TCPHSS 2012.) Column D; percent DO saturations of observed waters (Cols B & C) from nomograph. Column E; 'natural' water temperatures (Col. B values minus 3^{o}C). Column F; DO's at 100% saturation using 'natural' temperatures in Col. E from the nomograph. Column G; 'natural' DO's minus observed modern DO's (Col. F values – Col. C values). Column H; sizes of the DO "violations" (Col. G values – 0.2 mg/L). Grey shows nomograph calculations, yellow shows worst case "violation," 'natural' vs modern, in Col. H. (Observations were apparently attempted on July 12 but no data are listed in the source.)

3) Results. The Corrected Dissolved Oxygen Calculations.

As can be seen from Column G of Table 7-1, the largest difference between the DO levels of modern waters and 'natural' waters at 100% DO saturation would be about 1.17 mg/L, using 2010 observed water temperatures and DO's. The theoretical water quality "violation" on that date would be about 0.97 mg/L (Column H). The modelers' depiction of Capitol Lake (Figure 7-1) shows "violations" of about 4 mg/L in the 100%-saturated area – roughly four times the size of the one calculated here. Their calculation is in error for the south end of the Lake.

Suppose that the modern oxygen contents of the southernmost waters of Capitol Lake are really 4 mg/L below the 'natural' summertime levels that prevailed in pre-modern times. How cold would the 'natural' waters have to be, to hold that much more oxygen at 100% saturation? Table 7-2 shows a calculation of those 'natural' summertime water temperatures. Columns B and C are observed modern values as in Table 7-1. Column I shows how much oxygen the 'natural' water would hold if it had 4 mg/L more than at present. Column J (from the nomograph) shows the 'natural' water temperatures that would be needed for the pre-modern waters to hold 4 mg/L more oxygen than at present. Those 'natural' waters would need to be close to (or at) freezing levels to hold that much oxygen at 100% saturation.

4) Discussion. The Lake's Theoretical Water Quality Violations are Tiny or Nonexistent.

The modelers' depiction of DO "violations" (Figure 7-1) shows two other "red zones" (at the outlet of Percival Creek and at the dam) in addition to that in the southernmost Lake. Percival Creek, like the Deschutes River, experiences aeration from the rush of its water over a cataract just north of the Highway 101 bridge (at the Auto Mall). I expect that the theoretical violations at the Percival Creek outlet arise from the same initial conditions (thus creating the same errors) as in the Deschutes River case. The "red zone" at the dam is probably traceable to the inability of the salt water ponded there in the deep hole in the bottom to hold as much DO as the fresh water overlying it, compounded by the modelers' assumptions about past river temperatures.

A	B	C	I	J
Date (2010)	modern Temp (°C)	modern DO (mg/L)	assumed natural DO (C+4) (mg/L)	natural Temp (°C)
Apr 19	11.64	10.24	14.24	0.00
May 10	11.64	10.18	14.18	1.00
Jun 15	11.92	10.37	14.37	<0
Jul 12	15.83			
Aug 16	16.58	9.31	13.31	2.50
Sep 13	13.27	9.52	13.52	2.00

Table 7-2. Pre-modern ('natural') water temperatures needed to hold 4 mg/L more oxygen than modern waters at 100% saturation. Columns A, B, C observed modern data as in Table 7-1. Column I; DO levels higher by 4 mg/L than modern levels (C+4). Column J; 'natural' water temperatures needed to hold the amounts of oxygen in Column I at 100% saturation. Grey column is calculated from the nomograph.

Throughout the rest of the Lake, the green areas (Figure 7-1) show the success of plants at raising the water's dissolved oxygen level and reducing the sizes of the 'violations' shown by the modelers. There the per cent saturation of the water is unknown and unknowable and the nomograph correction can't be applied.

The violations shown by the modelers in the red zones are some 3+ mg/L higher than are indicated by the nomograph calculations. If the same absolute errors characterize the green zone (that is, 3 mg/L higher than "real" or "likely" over most of the Lake), then its "violations" would appear as shown in Figure 7-7b.

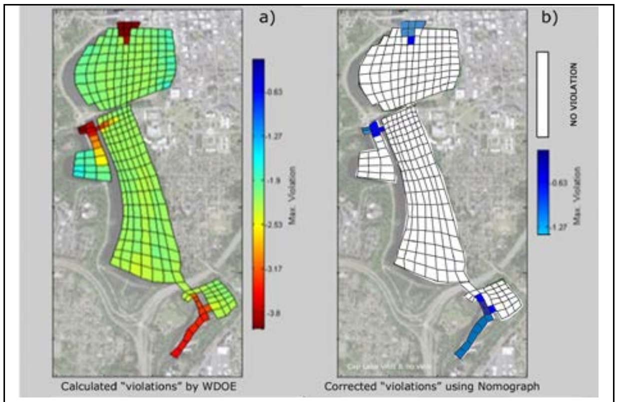

Figure 7-7. Theoretical WQ standards violations in Capitol Lake as calculated by the WDOE computer model (left) and as recalculated by the author using a nomograph (right). The value in each "blue zone" (right) is the violation calculated in Table 7-1. The "red zone" (left) violations are in error by about 3 mg/L. All other calculated violations in mid-Lake are about 2 mg/L or less. If they were also overestimated by 3 mg/L, the corrected Capitol Lake map (right) would show no significant violations at all.

Common sense and familiarity with real-world dissolved oxygen levels and changes should have prompted the modelers to take a second look at the enormous DO changes calculated by their model. Apparently they never did so. The result was a depiction of Capitol Lake, now widely disseminated, that has mislead everyone who has taken it at face value into believing that Capitol Lake has serious dissolved oxygen depletion conditions. Modern reality is that Capitol Lake's dissolved oxygen levels are always higher than the standard for the Deschutes River and (almost always) higher than the adjacent salt water DO levels at their highest.