The Department of Ecology's Supplemental Modeling Report.
A Critical Review.
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8. THE LATE-SEASON DEPARTURE OF ORGANIC CARBON

8-1. Ecology's "Organic Carbon" Hypothesis and the Real World Alternative.

After I (and others) suggested that Capitol Lake might be helping Budd Inlet resist low DO levels by removing Nutrient Nitrogen (NN) from the Deschutes River water, the Department of Ecology began looking for ways to downplay this positive feature of the Lake. The answer that they arrived at is this: "Yes, the Lake traps NN and stores it in plant biomass, but then the biomass itself immediately goes over the dam into Budd Inlet in the form of organic carbon, then decays and releases the trapped NN in the saltwater." Then, of course, marine phytoplankton growth would immediately follow in Budd Inlet with the sinking phytoplankton using up oxygen at the bottom as it decayed. In that scenario, the uptake of NN by the Lake would postpone oxygen depletion in Budd Inlet by only a few days – an insignificant protective effect. In all of their subsequent dealings, the code words "organic carbon" refer to this idea.

It is true that, sooner or later, some, most or even all of the new plant biomass formed each summer in the Lake must be eaten or break down and decay, releasing nutrients and using up oxygen in the process. The critical questions are "Where?" (in the Lake? Budd Inlet? both?) and "When?" ("sooner," during the summer growing season, or "later," after the growing season?)

The real-life story is that most of the organic carbon created in the Lake during summers either decomposes there or, if it leaves the Lake, does so after the main growing season, when its oxygen-consuming decomposition in Budd Inlet can do no harm. That is, most of the organic matter that escapes from the Lake does so "later," not "sooner" as in Ecology's claim. The following describes that real-life phenomenon.

8-2. Seasonal Change in Capitol Lake.

To people who visit Capitol Lake, the most familiar fact is that the whole Middle Basin and parts of the North Basin fill up with "weeds" every summer. The weeds' growth is made possible by the vast quantities of NN delivered to them daily by the Deschutes River. Those plants are the base of a food web that includes ducks, insects, and a few other animals that eat certain plants directly. When the plant parts break off, sink, and decay, they support legions of clams, worms, insects, snails, crustaceans, and bacteria, many of whom become food for fishes, otters, waterfowl, and even for bats and swallows. These other organisms capture and store some of the NN originally trapped by the plants – for the durations of their entire lifetimes or until they themselves are eaten.

The same tonnage of plants would be created and would decay if the Deschutes River nutrient nitrogen went directly into Budd Inlet. The effect of its decay or consumption in the Lake is to prevent that consumption from occurring in Budd Inlet.

All of the organisms that respire in the Lake water prevent oxygen consumption in Budd Inlet. But their eventual deaths and decay then release the NN contained in them. In the slow-moving Lake water, that released NN can be immediately recaptured by other plants and phytoplankton and again held for a long or short time in the Lake. A few such re-cycles of the NN, especially if the NN is taken up by large plants, can long delay or even prevent its eventual escape from the Lake.

The NN from the Deschutes River enters the Middle Basin at its farthest point from Budd Inlet. That Basin is a long water body shallow enough (average depth about 9 feet) for sunlight to penetrate to the bottom and for rooted plants to grow virtually everywhere.

The giant submerged "forest" of plants in the Middle Basin seems to be invisible to the Ecology modelers. Their attention is focused on phytoplankton – the small drifting single plant cells that are the mainstay of photosynthesis in most of the ocean and in some lakes. Figure 8-1 (upper graph, green line) shows Ecology's calculation of the amount of organic carbon produced in the Lake each year by plants *and released to Budd Inlet*. To arrive at that answer they must assume that *all plant growth in the Lake is by phytoplankton* – there can be no growth at all of large plants. The upper green graph accurately portrays the amount of organic carbon production – *but in real life the amount escaping to Budd would be so small that that line would be at the very bottom of their graph*. (This unrealistic Figure, shown here for reader recognition, is analyzed in depth in Chapter 7.)

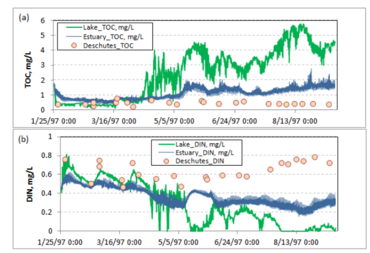

Figure 11. a) Total organic carbon (TOC) and b) dissolved inorganic nitrogen (DIN) concentrations at the location of the Capitol Lake dam under Lake (with the dam) and Estuary (without the dam) scenarios compared with concentrations in the Deschutes River at E Street.

Poster graph Grab2 > Figures

Figure 8-1. Ecology's calculations of organic carbon and nutrient nitrogen production in Capitol Lake or an estuary in the Lake basin. See Chapter 7.

The most abundant plants in Capitol Lake are a leafy submerged native species (*Elodea canadensis*) that grows attached to the bottom. Also abundant are native species of *Potamogeton*, rooted plants with flat oval or strap-shaped leaves that float at the surface (TMDL Appendix C, 2012). These and a few others (eg. introduced water lilies) make the water very unfavorable for phytoplankton in two ways. They shade the water beneath them (reducing the light available for phytoplankton growth) and they provide cover from predatory fish for zooplankters – copepods, rotifers, cladocerans and other tiny swimming animals that eat phytoplankton.

The rooted plants can only enter Budd Inlet if and when they break up and drift to the dam – in late summer. While growing, they "snag" floating masses of algae and duckweed and anchor them in the Lake until late summer as well.

The biomass of the rooted plants in Capitol Lake is at least 50 times that of the phytoplankton. (That calculation is shown in an Optional Technical Note section at the end of this Chapter.) In addition to their overwhelming biomass abundance, the rooted plants act as "platforms" for fuzzy blankets of tiny algal filaments that grow attached to the stems and leaves. Given this real-world ecology, *it is likely that phytoplankton make up*

2% or less of the plant production in the Lake. On Ecology's graph (Figure 8-1), that would be a green line so close to the bottom of the graph that it would be invisible.

With over 50 times the biomass of the phytoplankton, the large plants and their algal overgrowths get "first dibs" on the NN in the river water moving through the Middle Basin and take up about 58% of all of the NN delivered by the Deschutes River. The North Basin takes up some of the NN that escapes from the Middle Basin, removing by itself nearly 25% of the total NN delivered by the Deschutes River (Figure 34, CH2M-Hill 1978).

"Delay" is the name of the game. If the Lake plants can delay the escape to Budd Inlet of the nutrient nitrogen that they capture each summer (or the new organic carbon that they manufacture) until October or later, they can prevent those materials from depleting oxygen in Budd Inlet during September (the critical growing season). And several factors do indeed delay the escape of the Lake's new plant biomass each summer.

Figure 8-2. Floating plants and algal mats pushed toward and into the Middle Basin (behind the RR bridge) by wind from the north. The Middle Basin has surface plant mats piled by the wind and/or growing along its south shore in the distance. August 19, 2015.

The rooted plants stay put, except for pieces that break off and drift around. These pieces and floating algal mats are confined to the Middle Basin by three factors; partial blockage of the Basin's outflow by a railroad bridge at its north end, prevailing summer breezes from the north that confine the floating plants and algae to the south side of that bridge, and the anchoring effect of the rooted plants where the floating masses tangle with the surface leaves and stems. The deeper North Basin's plants are confined to that Basin's shores and shallow water. As in the Middle Basin, floating algal and plant masses are pushed southward by the prevailing summer breezes from the north, with the result that they accumulate along the shore farthest from Budd Inlet or are even pushed back southward under the railroad bridge into the Middle Basin (Figure 8-2). Occasional summer breezes blowing northward push floating algae (and trash) into an embayment at Heritage Park on the northeast shore, where this floating debris remains all summer long. These effects of the wind and Lake topography keep most of each summer's newly formed plant biomass in Capitol Lake until about October or later. In autumn the winds switch to their winter pattern (blowing regularly from the south) and begin to push floating Lake material toward Budd Inlet.

Figure 8-3. Floating plant matter trapped in the Heritage Park embayment where it remains all summer long. August 20, 2015.

Ecological processes contribute to the delay of NN passing through. Oxygen is consumed in the Lake – not Budd Inlet – whenever the newly created plant biomass is eaten or decays.[1] When that happens, the NN captured by the plants is released back into the water. The "residence time" of water in the Lake – the time elapsed between its entry from the Deschutes River at the south end and its departure to Budd Inlet at the north end -- is about 15 - 20 days. During that passage time the released NN can be taken up again by plants and again stored in new biomass. Cycling thus in the Lake much NN can reside there in plants throughout most or all of the summer growing season. Its best opportunity to move into Budd Inlet is after September. In late October uptake by plants stops and NN, now delayed in its journey to the sea by weeks or months, finally escapes from the Lake either dissolved in the water or in the biomass of senescent plants. (This cessation of uptake is shown in Figure 7-1 in Chapter 7 and also in Figure 8-5 below.)

Once the plant matter from Capitol Lake reaches Budd Inlet, there is one last mechanism of delay before it can start using up oxygen. Freshwater plant material is rich in cellulose, one of the most indigestible carbon compounds in nature. The plant biomass can drift for a long time and distance – perhaps entirely out of Budd Inlet -- before finally succumbing to the (mostly bacterial) processes that decay it.

Once the growing season is over, floating masses of plants begin to appear at the dam and go down the fish ladder into Puget Sound (Figure 8-4). Such sights are seen regularly during the fall, but only occasionally during the summer.

This scenario is described in a consultants' report on results of a Lake drawdown in 1997 (Entranco, 1997). The authors' expectations are that "… decay of the plants and algae occurs over a 60-day period at the end of the growing season, and … 100 percent of the nitrogen and phosphorus contained in plant tissue is contributed to the water column at that time …".

Figure 8-4. Floating mats of Capitol Lake plants at the dam exiting to Budd Inlet. October 28, 2015.

It is impossible to learn anything about this phenomenon from the Budd Inlet Model. The model's calculations stop on September 15 (Figure 8-5). The uptake of NN by the Lake via new plant growth continues until well into October, "beyond the edge of the universe" from the model's perspective. We must look to real, observed data for insight on this.

If "delayed release" of most of Capitol Lake's decaying

[1] Massive oxygen consumption in the Lake water can *never* deplete the DO level there, for reasons explained in Chapter 9.

plant material really occurs, one would expect large-scale consumption of dissolved oxygen in Budd Inlet during October and November when the main mass of dead plant matter surges out of Capitol Lake and into the Inlet. In fact, there is an observed overall decline in DO through early fall culminating in levels below the water quality standards in the central and outer Inlet by late November at all depths, with recovery in December. Figure 8-6 shows this phenomenon during Fall 1996 at station BC-3 near the west-side Tykle Cove shore (BISS, 1998).

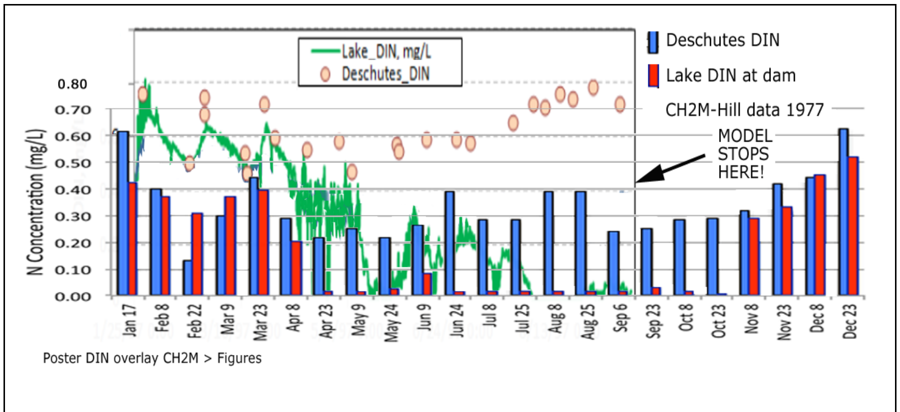

Figure 8-5. Budd Inlet Model prediction of Dissolved Inorganic Nitrogen (DIN) in Capitol Lake compared with observed data. The Model simulation ends while DIN uptake in the Lake is still continuing through mid-September and October. Superposition of Figures 7-1 (1977 data, CH2M-Hill) and 7-3b (1997 Poster- and SM Report - data and graph in Organic Carbon section, Chapter 7. The green graph is that in Fig. 8-1b above.) CH2M-Hill data (bars) are from 1977, SM graph and data points are from 1997.

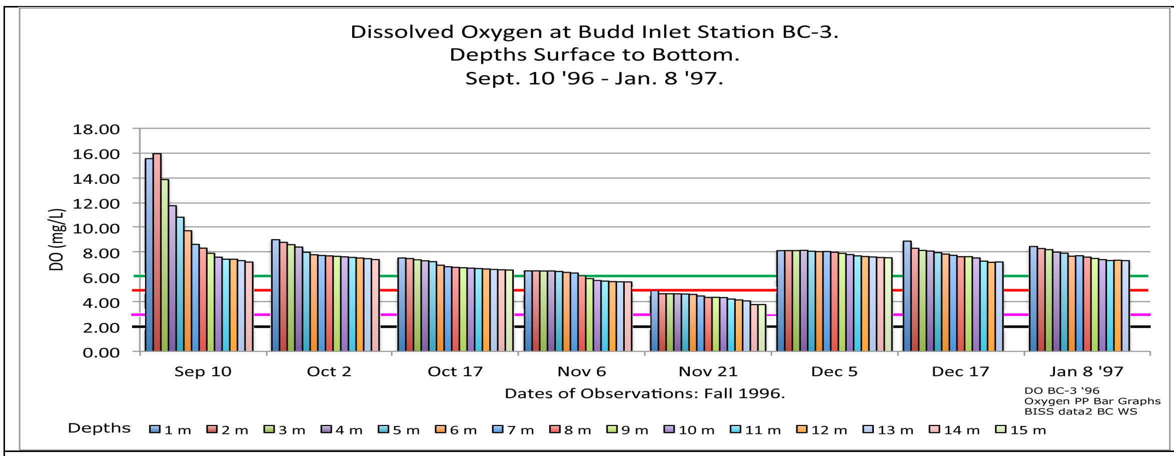

Figure 8-6. Dissolved oxygen vs. depth at station BC-3, central Budd Inlet, September 10 1996 – January 8 1997. In each group surface DO is leftmost bar, bottom DO is rightmost bar. Lines are 6.0- and 5.0-mg/L (green and red, DO standards), 3.0 mg/L (purple, low DO stress level), and 2.0 mg/L (black, low DO acute stress level). Source: BISS 1998.

This effect can be seen at stations in Budd Inlet from BF-3 near Boston Harbor to BB-1 opposite Priest Point Park. It is not detectable from the BA stations inward to the heads of East and West Bay.

This pattern is what we might expect if the DO drop is due to the decay of escaped Lake vegetation in late Fall. That is when Lake plant uptake of nitrogen nutrients and growth ceases for the year (see Figure 8-5 above) and when mats of vegetation break loose and drift to and over the dam. The Lake plants, unlike phytoplankton, are composed of decay-resistant cellulose and would not be expected to start depleting the Inlet's oxygen in the inner harbor immediately after entry. The following analyzes this possibility.

8-3. Background for Understanding the Late Fall Decline in Dissolved Oxygen in Budd Inlet.

To investigate the late Fall drop in Budd Inlet's dissolved oxygen levels, I examined DO data collected during the BISS research conducted during fall and early winter of 1996. (The BISS study ended in September 1997, hence the need to look at 1996 fall data.)

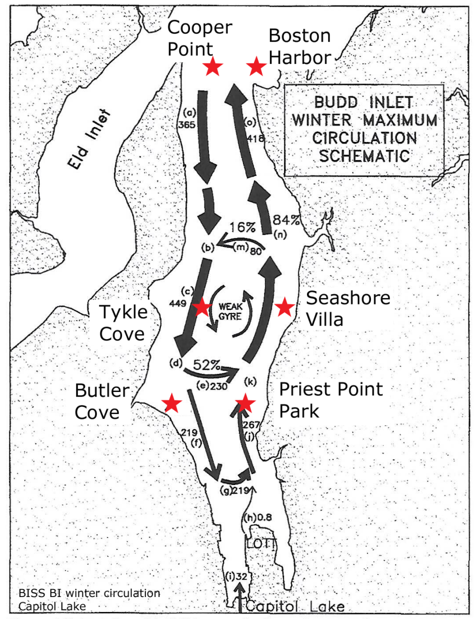

Figure 8-7. Circulation of water in Budd Inlet. Winter. Widths of arrows show sizes of flows. Stars show stations discussed in the text. Source: BISS 1998.

Figure 8-7 shows the winter circulation pattern of water in Budd Inlet. (Summer circulation is the same, but the numbers are slightly different.) A massive stream of water enters the Inlet along the western shore. Mostly hugging the bottom, it heads southward, then turns and crosses Budd Inlet north of the Port Peninsula. That stream then heads northward along the eastern shore, now nearer to (or at) the surface. Some of it turns and re-enters the incoming stream, but the rest (some 80+ %) exits Budd Inlet at Boston Harbor. This is the "estuarine circulation," entirely independent of the tides, described in Chapter 1.

The "residence time" – that is, the average amount of time during which incoming water remains in the Inlet before leaving again – is about 8 days in winter and 12 days in summer (BISS, 1998). The BISS authors describe this non-stop year-round flow as "strong circulation."

The incoming salt water has characteristics acquired in Puget Sound outside Budd Inlet. While it is in the Inlet, Capitol Lake impresses it, more or less, with its own fresh water "signature." The BISS stations are numbered such that the "3's" are along the west shore, influenced by the incoming stream; the "1's" are along the east shore, influenced by the outgoing stream (the "2's" are in the center; see Figure 2-2 Chapter 2). Thus station BC-3 (Figure 8-7, Tykle Cove) is near the west shore and is more heavily influenced by water entering Budd Inlet than by water exiting the Inlet. By comparing the west shore and east shore stations, we can try to detect Capitol Lake's "signature" in the Inlet water.

8-4. Incoming and Outgoing Water; The Fall Seasonal Effect on Dissolved Oxygen.

Figure 8-8 compares stations DO levels at BC-3 (west shore) and BC-1 (east shore).

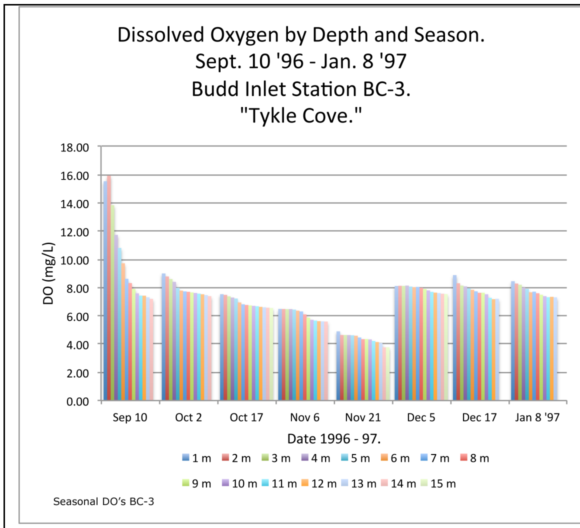

Figure 8-8a. Oxygen levels in incoming water at the position of Tykle Cove, west shore of Budd Inlet. Each group of bars shows DO's ranging from the surface (leftmost bar of group) to the bottom (rightmost bar) on each date. Source: BISS spreadsheet 1998. [This repeats Figure 8-6 above.]

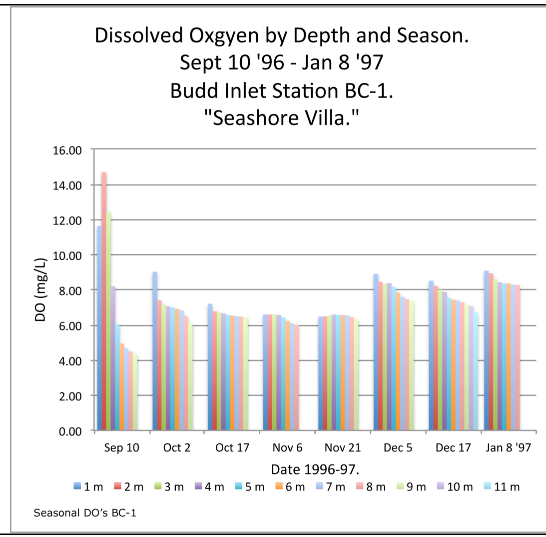

Figure 8-8b. Oxygen levels in outgoing water at the position of Seashore Villa, east shore of Budd Inlet opposite Tykle Cove. Format as in Figure 8-8a. Source: BISS spreadsheet 1998.

During September, DO levels are lower – *much* lower at the bottom -- in the outgoing water than in the incoming water (respectively BC-1, Fig. 8-8b and BC-3, Fig. 8-8a). During its passage, processes that deplete oxygen in innermost Budd Inlet remove DO from the incoming water before the flow takes it back outward. From October through early November, DO's are about the same in the outgoing water as in the incoming water, gradually declining along the incoming (west) shore while holding steady along the outgoing (east) shore. In November, the DO in the incoming water reaches the lowest point in its decline, but is dramatically restored by the time it begins its exit via BC-1. After November the incoming and outgoing waters have roughly the same amounts of dissolved oxygen.

That pattern suggests that something is reducing DO outside Budd Inlet. The "something" may be decaying Lake vegetation – but it almost certainly includes a much greater regional effect of decaying terrestrial leaves entering the water everywhere around Puget Sound on a grand scale at this time of year (Figure 8-9).

Figure 8-9. Autumn leaves with Lake vegetation mat near dam. Nov. 1, 2015.

Figure 8-10 shows a composite view of this oxygen pattern as the water passes through Budd Inlet. In that Figure, the DO at each depth at BC-3 (Tykle Cove) has been subtracted from the DO at the same depth at BC-1 (Seashore Villa) to show the change in DO as the water passes from BC-3 (inbound) to BC-1 (outbound). Where the result is negative, the water has lost oxygen during its passage from the west side around to the east side. Where the result is positive, the water has gained oxygen. The late-summer removal of oxygen from the water is very strong in September. A startling recharge occurs in November. These changes, *both* occurring *at all depths* are the most prominent features of this pattern.[2]

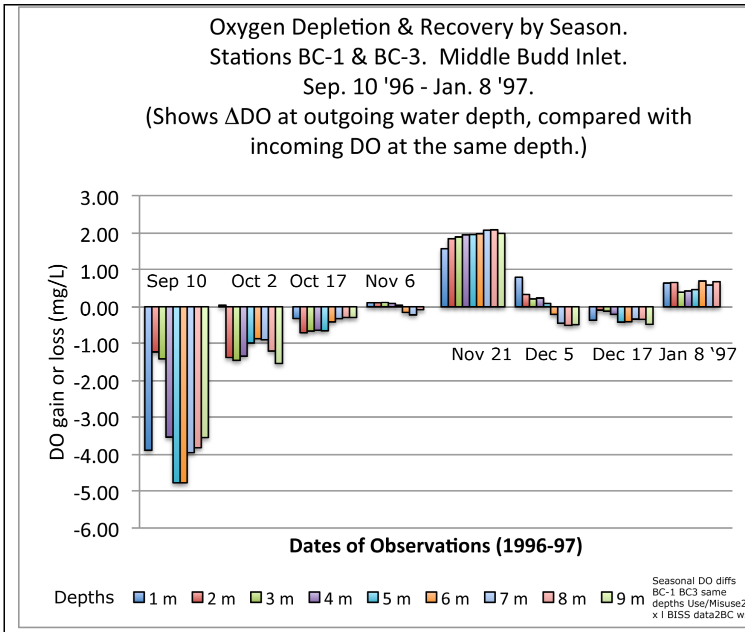

Figure 8-10. Changes in oxygen levels in water at all depths between entry to Budd Inlet (BC-3, Tykle Cove) and exit from Budd Inlet (BC-1, Seashore Villa). Bars show (DO at BC-1) minus (DO at BC-3) for water of the same depth, both stations. Negative values show loss of oxygen from water, positive values show gain of oxygen by water. Data for these subtractions are shown, bar by bar, in Fig. 8-8 above. Rightmost bar of each group shows the bottom water of the shallowest station, each comparison.

Comparisons between stations BB-1 and BB-3 (Priest Point area) and BF-1 and BF-3 (Boston Harbor area), not shown here, show the same patterns. This appears to be a general pattern of oxygen exchange throughout Central Budd Inlet.

Figure 8-11 shows the changes in water density with depth and season at station BC-1 (Seashore Villa) in Fall 1996. The water is strongly stratified in September and even more so in early October ("bent" curves) due to reduced salinity and residual summer high temperatures at the surface. The effect is to isolate deeper water from contact with the atmosphere, preventing atmospheric oxygen from replenishing oxygen consumed by processes near the bottom. By November 6, stratification has mostly disappeared ("straightening" the curves, due to cooling at the surface) and the water begins to mix from surface to near-bottom.

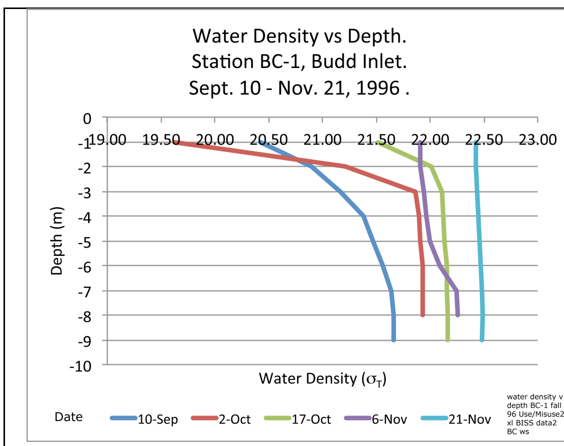

Figure 8-11. Density of water vs. depth at Budd Inlet station BC-1, Sept. 10 – Nov. 21 1996. Source: BISS spreadsheet 1998. [Density = $(\sigma_T/1000) + 1$ g/mL.]

[2] Bottom water rises, some of it all the way to the surface, as it penetrates farther into Budd Inlet. An alternative Figure comparing incoming water with outgoing water shallower by 1 meter (not shown) is almost identical to this one (Fig. 8-10) comparing DO's at the same depths.

The effect is to expose the whole water column to the full blast of oxygen uptake from the atmosphere. Even if there is massive consumption of oxygen by decomposition of organic matter from Capitol Lake and autumn leaf-fall at this time, this huge seasonal re-oxygenation of water from the atmosphere would overwhelm it. If that is the case, then Capitol Lake may release its decaying vegetation at exactly the right time to have zero effect on Puget Sound.

8-5. Summary. The Search for a Late-Season Lake Effect.

Several real-life phenomena support the idea that decay of plants from the Lake does not cause oxygen depletion in Budd Inlet during the growing season. These are:

1) The Lake plants continue to take up nitrogen from the Deschutes River water (and thus continue to grow) until late October (Fig. 8-5);

2) Most of the plant biomass in the Lake is rich in cellulose, a material that does not decay quickly and hence has time to drift out of Budd Inlet before decaying;

3) Mats of uprooted or detached Lake plants can often be seen drifting over the dam in fall but seldom in summer (Fig. 8-4);

4) Seasonal winds blow drifting surface plants (detached algae and larger plants, duck-weed, etc.) southward away from the dam during the summer and concentrate them in the Middle Basin, along the south shore of the North Basin, and in the northeast shore entrapment area of the North Basin (Figs. 8-2, 8-3);

5) Persistent low and decreasing levels of dissolved oxygen develop after the growing season throughout central and outer Budd Inlet, at a time and location where one would expect the Lake vegetation to begin to decay after its escape to the Inlet.

Items 1- 4 are not in doubt. The late-season depletion of oxygen in the outer Inlet mentioned in Item 5 is, however, likely due to the decay of terrestrial vegetation (including fallen autumn leaves) from everywhere around South Puget Sound. The stream of external water entering Budd Inlet (volume 219 m^3/sec) is nearly seven times the size of the stream exiting the Lake (23 m^3/sec, Fig. 8-7); this could dilute any Lake effect beyond recognition in the BISS data.

The only way to test this alternative hypothesis is by way of a year-long program of field observations in which organic carbon in floating biomass, phytoplankton, and dead particulate/dissolved material is directly measured. It is impossible for the Budd Inlet model to evaluate this hypothesis. The findings of a field study would be decisive for determining whether organic matter from Capitol Lake is – or is not – having an adverse impact on Budd Inlet.

8-6. Optional Technical End Note: Ratio of Biomass Between Macrophyte (Large) Plants and Phytoplankton.

The ratio "macrophyte carbon/particulate organic carbon" was calculated by me from Lake data for September 2004. Particulate Organic Carbon (POC) values in mg/L concentrations were taken from Figures H13 - H14, TMDL Appendix H, by scale measurement and interpolation. (Appendix H's misprinted "Matlab" graph scale is actually mg POC/L; Kolosseus, pers. comm.)

The average mg/L value for the whole lake in September was multiplied by the volume of the Lake to obtain total mass of POC in the Lake. September macrophyte dry weights in gm dry weight/m^2 were obtained from Figure H11, Appendix H, also by scale measurement and interpolation.

The total dry weight for the whole Lake was obtained by multiplying the average gdw/m^2 by the area of the Lake. The ratio "macrophyte dry weight/POC" is 56:1 by this calculation.

Since the carbon in living phytoplankton is only a fraction of the total POC (say half, usually less), the ratio of macrophyte- to phytoplankton carbon is probably even greater; say about 100:1.