6. THE LATE-SEASON DEPARTURE OF ORGANIC CARBON. AN ALTERNATIVE HYPOTHESIS.

6-a. WDOE's "Organic Carbon" Hypothesis and an 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.

WDOE's proposal is a valid scientific hypothesis. 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?)

In the spirit of good science, here is an alternative hypothesis. That is, 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. This hypothesis is that most of the organic matter that escapes from the Lake does so "later," not "sooner" as in Ecology's hypothesis. In the following, I cite evidence that this alternative hypothesis fits the facts better than the Department of Ecology's hypothesis.

6-b. Seasonal Change in Capitol Lake.

To members of the public who visit Capitol Lake, the most familiar fact is that the whole Middle Basin and some 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 the 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. All of the organisms that respire in the Lake water as they consume this material prevent an equal amount of oxygen consumption in Budd Inlet. Their deaths and decay release the NN contained in them – but 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 recycles 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 everywhere. This giant submerged "forest" of plants (with over 50 times the biomass of the phytoplankton;[1]) gets "first dibs" on the NN in the river water moving through it and takes up about 58% of all of the NN delivered by the River (58% figure from Figure 34, CH2M-Hill 1978).

Figure 6-1. 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.

Several factors delay the escape of each summer's new plant biomass from the Middle Basin. The rooted plants stay put except for pieces that break off and drift around. 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 tend to hold the floating algae on 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 (which take up nearly 25% of the total NN delivered by the River) 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, 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 6-1). This effect of the wind probably keeps most of each summer's newly formed plant biomass in Capitol Lake until about October.

"Delay" is the key word. The Lake intercepts NN and uses it to build new plant biomass. If that new biomass is eaten or decays in the Lake, the NN released is again recaptured. Its best opportunity to move into Budd Inlet is after September, October and November,

[1] The ratio "macrophyte carbon/particulate organic carbon" was calculated by me from Lake data for September 2004. POC values in mg/L concentrations were taken from Figures H13-H14, TMDL Appendix H by scale measurement and interpolation. (The graph "Matlab" 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 even greater; say about 100:1.

when plant growth stops and NN, now delayed in its journey to the sea by weeks or months, finally escapes to Budd Inlet. Delay also results from the fact that escaping freshwater plant material is rich in cellulose, one of the most indigestible carbon compounds in nature. It can drift for a long time and distance before finally succumbing to the (mostly bacterial) processes that finally decay it.

Capitol Lake continues to take up NN well into October (see Figures 3-1 and 3-2). After that time (I expect), plant growth ceases for the year, masses of senescent plant material break loose and (pushed by the prevailing southwest winds of that season), finally make their way into Budd Inlet (Figure 6-2). That is when (I expect) their decay begins to use up a lot of oxygen in the salt water.

Figure 6-2. Floating mats of Capitol Lake plants at the dam exiting to Budd Inlet. October 28, 2015.

This scenario is taken for granted by the authors of a consultants' report on results of a Lake drawdown in 1997 (Entranco, 1997). Their expectation is that "… decay of the plants and algae occurs over a 60-day period at the end of the growing season, and that 100 percent of the nitrogen and phosphorus contained in plant tissue is contributed to the water column at that time …" with this daily loading (2 kg P and 16 kg N) constituting only about 2% of the phosphorus contributed to Puget Sound by the river during this time. (The % contribution of nitrogen is not mentioned.) (Entranco, p. 28, 1997).

It is impossible to learn anything about this phenomenon from the Budd Inlet Model. As shown in Figure 6-3, the model's calculations stop on September 15. 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 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

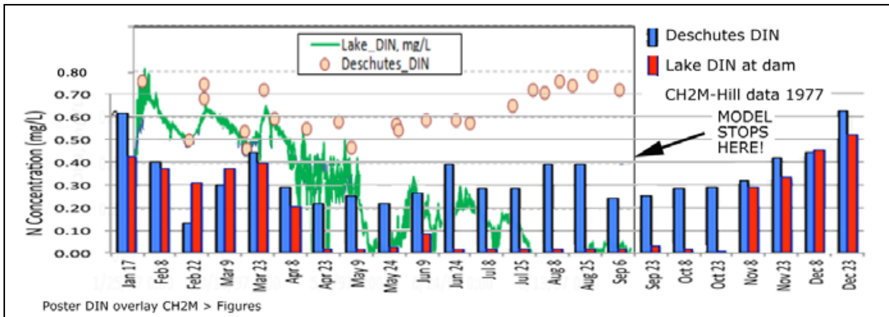

Figure 6-3. Budd Inlet Model prediction of Dissolved Inorganic Nitrogen (DIN) in Capitol Lake compared with observed data. Model simulation stops while DIN uptake in the Lake is still continuing through mid-September and October. Superposition of Figures 3-1 (1977 data, CH2M-Hill) and 3-3b (1997 Poster- and SM Report- data and graph in Organic Carbon section, Section 3.)

Lake and into the Inlet. The situation is clouded by the fact that trees and other land plants shed their leaves at this time, around and into South Puget Sound. The plant material that enters the water virtually everywhere during the fall has the same effect on the dissolved oxygen of the whole Sound as would rafts of dead material from Capitol Lake.

How to sort out the Lake effect in Budd Inlet? My analysis is based on the circulation pattern of Budd Inlet and an assumption that the Lake's huge summer-long accumulation of aquatic plant matter driven by nitrogen from the Deschutes River briefly outweighs the autumn leaf-fall effects of trees along the River, smaller streams, and the shoreline of Budd Inlet in its relatively confined waters.

6-c. Background for a Test of the Alternative Hypothesis.

To investigate this hypothesis, I used DO data collected during the BISS research conducted during fall and early winter of 1996. (The BISS study concluded in September 1997, before the fall 1997 months of interest here.)

Figure 6-4 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, which simply move the whole pattern northward and southward. 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 pattern as "strong circulation." As can be seen from data in TMDL Appendix G2, water leaving Capitol Lake proceeds northward from the mouth of West Bay where it begins to influence this incoming stream (Figure 6-5). 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." By comparing the properties of the incoming and outgoing waters might we detect Capitol Lake's effect? (The "effect" we are looking for is a big drop in DO levels in the Inlet during October and/or November.)

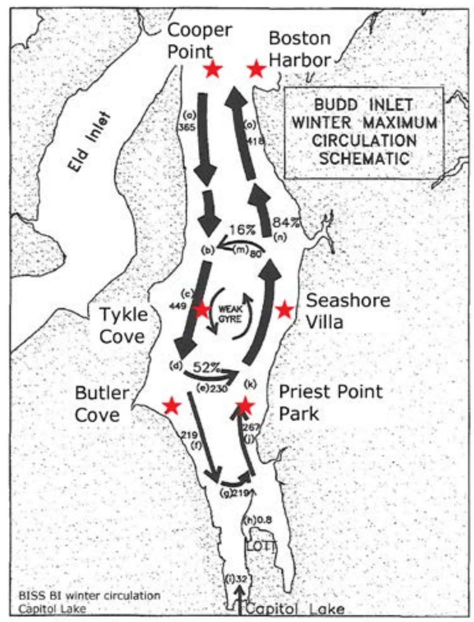

Figure 6-4. Circulation of water in Budd Inlet. Winter. Widths of arrows show sizes of flows. Stars show stations discussed in the text. Source: BISS 1998.

To anticipate the Results … no clear effect was detected. But this comparison identifies something else quite remarkable that may be happening. That is, if most of the Capitol Lake biomass really does enter the Sound during October and November, it may decay without having any negative effect on Budd Inlet dissolved oxygen whatsoever. At that time, Capitol Lake organic carbon may run into the underwater equivalent of an "oxygen blast furnace" that disposes of it once and for all.

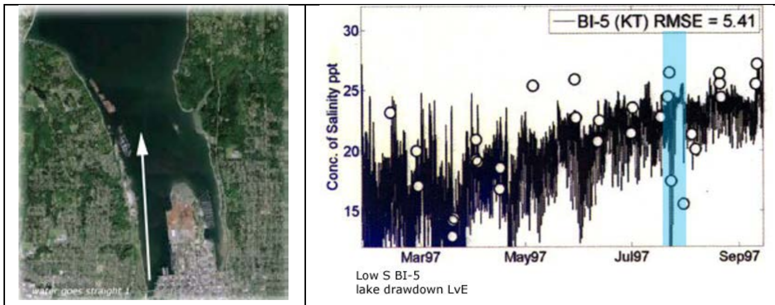

Figure 6-5. a) Direction of surface water movement from West Bay as indicated by data in TMDL Appendix G2. b) Example of Appendix data showing drastically reduced surface salinity at West Bay site BI-5 during dates of a massive freshwater discharge from Capitol Lake (highlighted). This pattern is strongly evident at BI-6 (near the dam) and weakly present at BI-4 (at the mouth of West Bay). There is no surface salinity decline at East Bay stations BI-2 and BI-1, nor is it detectable in the Appendix or BISS data at the BA and BB stations for these dates. [2]

6-d. Methods. The Search for a Late-Season Lake Effect.

The search for an effect is a three-part process, illustrated by the next three Figures. First, we examine the DO levels of representative stations BC-3 (Tykle Cove) and BC-1 (Seashore Villa) in Figures 6-6 and 6-7 at all depths, from surface to bottom.[3] We then examine fall season phenomena that affect mixing of the water from top to bottom. Finally, we directly compare the waters of stations BC-3 and BC-1 for insight on what's happening to dissolved oxygen in the Inlet.

Part 1. DO levels of incoming- and outgoing water in mid-Budd stations.

Figures 6-6 and 6-7 show DO levels at stations BC-3 (incoming water) and BC-1 (outgoing water) for dates from September 10 1996 through January 8 1997.[4] The incoming water shows less and less dissolved oxygen as the fall progresses, dropping to below the water quality standard for the BC-3 station by early November (6 mg/L; see Figure 5-9a). The outgoing water generally has slightly lower DO levels than the incoming water from September through mid-October, then switches over to higher levels in November. It is in November that we would look for a "decaying vegetation effect" due to Capitol Lake, namely a depression of DO levels. As shown in the Figures, we find the opposite – an

[2] The only other graphs in Appendix G2 that show this lake effect are those for "CBOD," carbon biological oxygen demand. No observed data are shown in these graphs, only computer calculations. These calculations show the lake effect occurring strongly at stations BA-2 and BB-2, with a feeble hint of an effect at BI-2. This is useful as a trace of where the computer "thinks" the water from the Lake goes after it enters West Bay. That is, directly outward, not over toward East Bay.

[3] The names and positions of stations referred to in this section are shown in Figure 1-2 of section 1 and also in Figure 6-4, this section.

[4] Fall 1996 data are used for this analysis, since the BISS DO data don't show Late Fall 1997 DO's.

increased DO level. Either there is no Capitol Lake effect at this time, or something else is happening that swamps it. A "something else" may be recognizable from the following.

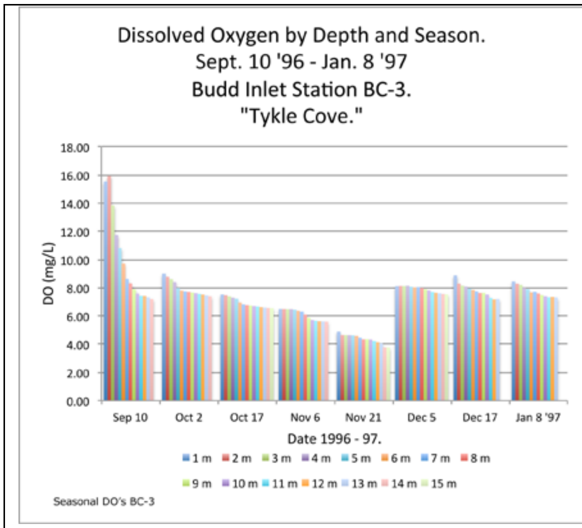

Figure 6-6. Oxygen levels in incoming water at the position of Tykle Cove, west shore of Budd Inlet. Each group of bars shows DO's ranging from the surface (leftmost bar of group) to the bottom (rightmost bar) on one of eight different dates. Overall DO's decrease from Sept. 10 through Nov. 21, then increase abruptly. Source: BISS spreadsheet 1998.

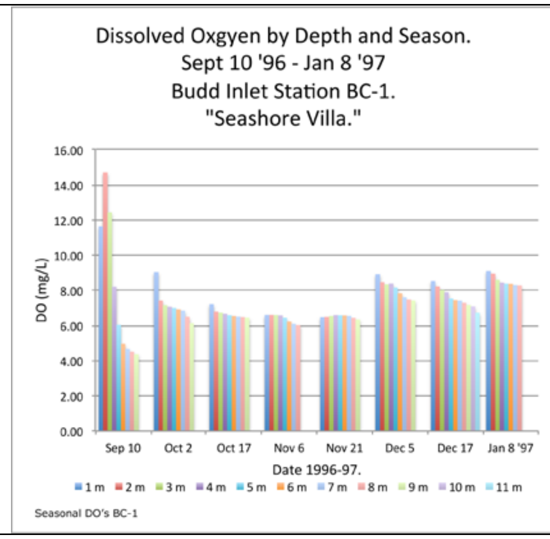

Figure 6-7. Oxygen levels in outgoing water at the position of Seashore Villa, east shore of Budd Inlet opposite Tykle Cove. Oxygen levels are less in deep water at BC-1 than at BC-3 in September, then about the same as at BC-3 on dates Oct. 2 – Nov. 6 on the west shore, then jump up rapidly after Nov. 21. Source: BISS spreadsheet 1998.

Part 2. Oxygen Uptake from the Atmosphere in November.

Figure 6-8 shows the change in stratification of the water along the east shore of Budd Inlet at station BC-1 (Seashore Villa) from September 10 through November 21, 1996. The water is strongly stratified in September and even more so in early October due to reduced salinity at the surface (not shown here). The effect is to isolate deeper water from contact with the atmosphere, enabling oxygen-consuming processes to deplete DO levels in deep water. By November 21, stratification has disappeared (due to cooling at the surface) and the water is well mixed from surface to bottom. The effect is now to expose the whole water column to the full blast of oxygen uptake from the atmosphere. Even

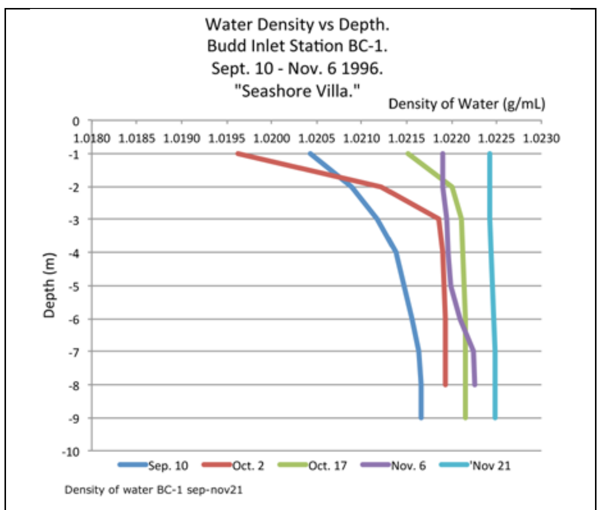

Figure 6-8. Density of water vs. depth at Budd Inlet station BC-1, Sept. 10 – Nov. 21 1996. Source: BISS spreadsheet 1998.

if there is massive consumption of oxygen by decomposition of organic matter from Capitol Lake at this time, this huge seasonal re-oxygenation of water from the atmosphere would probably 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.

Part 3. Massive Re-Oxygenation of All Depths in Budd Inlet in Late Fall.

Figure 6-9 shows a view of this reoxygenation process in action. In this 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 removal of oxygen from the water is very strong in September, moderate through October, and near zero (no change) on Nov. 6. On November 21, a startling surge in reoxygenation of the water at all depths takes place. Afterward oxygen is lost from the water in small amounts through December, then regained in small amounts in January 1997.

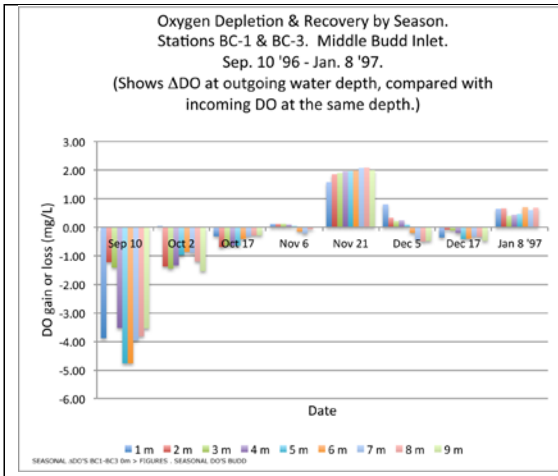

Figure 6-9. Changes in oxygen levels in water at all depths between entry to Budd Inlet (BC-3, Tykle Cove) and exit from Budd Inlet (BC-1, Seashore Villa). Bars show (DO at BC-1) minus (DO at BC-3) for water of the same depth, both stations. Negative values show loss of oxygen from water, positive values show gain of oxygen by water. Loss continues through October, large uptake occurs in November, little change occurs afterward.

Comparisons between stations BB-1 and BB-3 (KGY area) and BF-1 and BF-3 (Boston Harbor area), not shown here, show the same patterns. Comparisons in which the water at each depth on the east side is compared with the water one meter deeper on the west side, also not shown here, also show this pattern. This appears to be a general pattern of oxygen exchange throughout Central Budd Inlet.

6-e. Conclusions. The Search for a Late-Season Lake Effect.

The alternative hypothesis – most of the organic carbon that escapes from the Lake leaves and decays late in the growing season (September – November) is “not supported” by these data. But neither is the hypothesis disproved. It is possible that the rush of atmospheric oxygen back into the water in November swamps the predicted effect. The stream of water shown exiting Capitol Lake (Figure 6-4) (volume 32 m^3/sec) mixes with an incoming stream whose volume is 219 m^3/sec – that is, nearly seven times the size of the stream carrying the organic matter from the Lake. This may dilute the Lake effect beyond detection in the BISS data. Or perhaps there really is no Lake effect at all during the fall.

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 – and only a field study can answer these questions -- would be decisive for determining whether organic matter from Capitol Lake is – or is not –having an adverse impact on Budd Inlet.