The Department of Ecology's Supplemental Modeling Report. A Critical Review.
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10. LOW DISSOLVED OXYGEN IN NATURAL ESTUARIES.

10-1. The Drive to Sanitize Natural Estuaries.

"Eld Inlet has no dam and never has any low oxygen problems."

These words, spoken as "proof" that Budd Inlet's seasonal low oxygen levels were due to the dam that impounds Capitol Lake, were by a "Remove The Dam" advocate, a worker at the Thurston County Department of Health (Havens, pers. comm. 2013).

She couldn't have been wronger. Her mistaken view is that of many estuary advocates, who consider that "natural" is always better than "human impacted." In fact dissolved oxygen levels in undammed Eld Inlet are worse than those in modern Budd Inlet.

The Department of Ecology's Budd Inlet modelers have recently modified their computer model to "show" that "natural" (= pre-modern) Budd Inlet had no low oxygen episodes that would violate modern water quality standards (Figure 10-1). This is an example of their standard practice of revising the model to try, try again whenever it obstinately shows that Budd Inlet is improved by the presence of Capitol Lake. In this latest case, I expect that the revision of the model stems from its demonstration that pre-modern ("natural") Budd Inlet is about as plastered with water quality violations as is modern Budd Inlet with the dam (Figure 10-2).

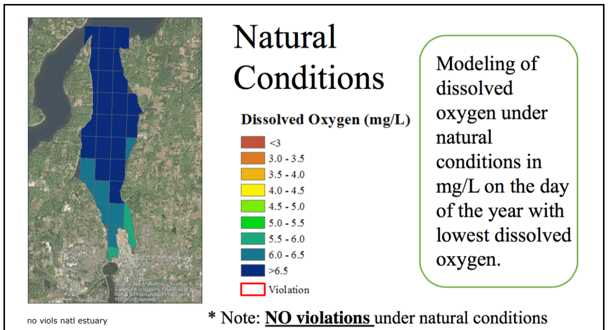
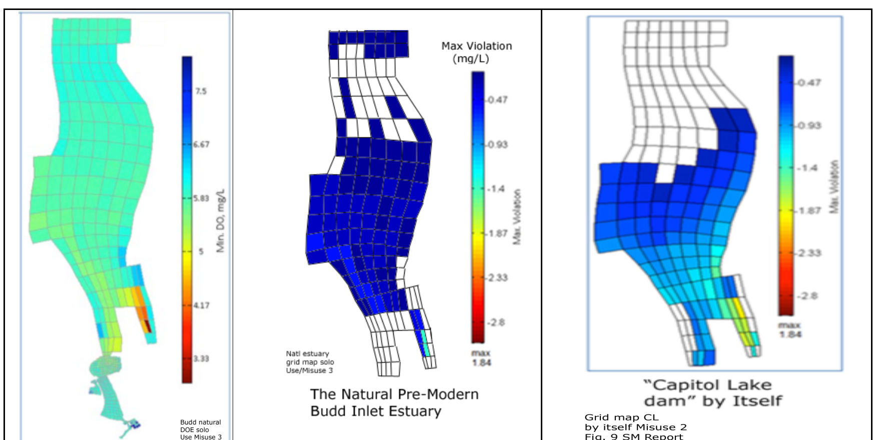


Figure 10-1. Slide from an Ecology presentation showing ***NO violations*** *[Ecology's emphasis] in the simulated pre-modern "natural" Budd Inlet. Source: Weiss, 2017.*

Figure 10-2c seems to show that modern Budd Inlet with Capitol Lake is not much worse off than the Inlet was in pre-modern times with no dam (Fig. 10-2b), a sign that addition of the dam has actually prevented deterioration of the oxygen situation in modern



a) The natural Budd Inlet. Ecology's portrayal.	b) The natural Budd Inlet. Conventional grid map portrayal of violations.	c) The modern Budd Inlet showing calculated violations "caused" by the dam.

times.

Figure 10-2. "Natural" Budd Inlet (a and b) and modern Budd Inlet (c) showing calculated violations of modern dissolved oxygen standards. a) Natural Inlet violations shown by Ecology in an opaque non-standard format; b) Natural Inlet violations converted to a standard grid map format (see Chapter 4); c) Modern Inlet violations shown by Ecology in the standard grid map format. Sources: a) SM Report's Fig. 7b, p. 32; b) derived from 10-2a in Chapter 4, this Review; c) SM Report's Fig. 9, p. 34.

Given the forces at work in estuaries – in particular those bearing down on East Bay (see Chapter 6) -- it is very unlikely that those water bodies went through the seasons in pre-modern times without ever experiencing DO levels lower than modern water quality standards.

This Chapter assesses what we can know about estuarine DO conditions in pre-modern times, using Eld Inlet as a specific example and all of Puget Sound as portrayed by another one of Ecology's computer models.

<u>10-2. Eld Inlet – A Modern "Natural" Estuary?</u>

Figure 10-3 shows Eld and Budd Inlets with a few important labeled features. The main streams driving Eld Inlet's estuarine circulation are the (very small) Perry and McLane Creeks. Their combined volumes in September, 2009, at 3.7 cfs were only 4% that of Budd Inlet's Deschutes River (TCPHSS 2010). Their low stream flows are probably the reason for the inlet's frequent low oxygen episodes.

Figure 10-3. Eld and Budd Inlets. (Source: Google Earth Image June 24 2017.)

Eld Inlet is closer to its pre-modern condition than Budd Inlet in the following ways:

1) The watersheds of its two main creeks are rural, forested, and non-urbanized;

2) Its shores are lined by residences and residential activities, not urban structures and activities;

3) The nutrient nitrogen levels in the creeks entering the inlet are very low – among the lowest of all South Sound streams;

4) It has not been dammed;

5) It is not extensively used for recreational boating or commercial shipping;

6) It does not receive treated wastewater from any (significant) WWTP's.

Eld Inlet differs from Budd Inlet in one way that is a departure from the "natural" condition; it is extensively farmed for shellfish. Budd Inlet has no such aquaculture.

10-3. Low Oxygen Levels in Modern Eld Inlet.

During the late 1990's, shellfish growers became concerned about the deaths of oysters planted in upper Eld Inlet. They began a research project, assisted and supported by the Department of Ecology, focused on the oxygen content of the water. A permanent measuring device ("probe") was established on the intertidal mud at the +1 foot >MLLW tide level (Figure 10-4, also Figure 10-3). Except for times when the tide dropped below that level (thus exposing the probe to air), *the device made DO measurements every 15 minutes throughout the whole summer seasons* of years 1998, 1999, and 2000.

Figure 10-4. Location of the Eld Inlet Dissolved Oxygen Probe at the +1' tide level. (See also Figure 10-3.) Google Earth Image provided by Pacific Shellfish Institute.

These probe data were graciously made available to me in the form of a spreadsheet (Pac. Shellfish Inst. Spreadsheet, 2000).

An example of the probe's DO measurements between 7:45 PM June 18 and 3:45 PM June 19 (1999) with the tide levels at those times is shown in Figure 10-5. In this example, the DO level was below 3.0 mg/L for the whole time shown and below 1.0 mg/L for most of that time – a deadly "worst case scenario" for marine life.

A "low-DO episode" as defined in this example is the length of time between the first decline of the dissolved oxygen level to below 5.0 mg/L and its first return back to that level or higher. The durations of the episodes in the Eld Inlet record that I have assessed range from 15 minutes to several days. Figure 10-6 shows the durations of 24 episodes of DO lower than a DO standard (5.0 mg/L) during July 1998, the last episode of which continued into August. Figure 10-6 also shows the lowest DO levels reached in each of these episodes. Early in the month the episodes are brief 15- or 30-minute "dips" below the DO standard, all higher than 4.0 mg/L, then they begin to last longer and show more drastic drops to stress-causing levels as the season advances.[1] (The Budd Inlet model, with its iteration interval of six minutes, is capable of detecting such dips.)

[1] A DO level of 3.0 mg/L is stressful for most marine organisms. Mild distress for the most sensitive species starts at about 4.5 mg/L and acute distress is experienced by almost all of them at about 2.0 mg/L. See Vaquer-Sunyer and Duarte, 2008 in References.

It is worth noting that the probe and the extreme low DO levels it measured were in a part of Eld Inlet that is comparable to the Budd Inlet headwaters that would be created if estuarine tidal marine water was returned to the Capitol Lake basin by dam removal.

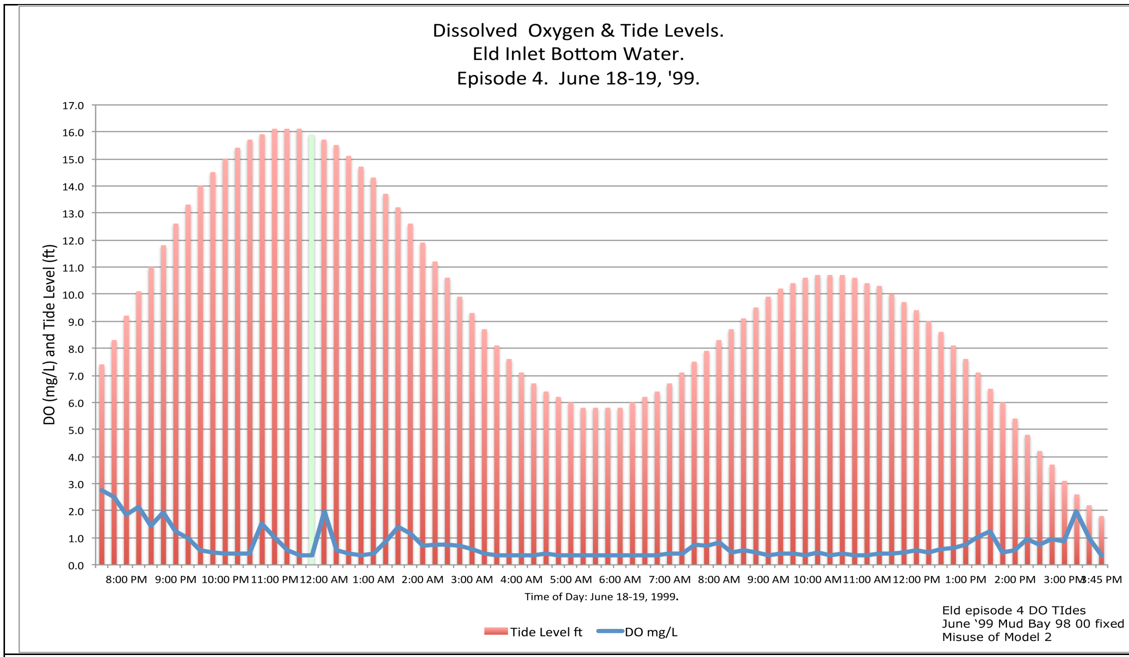


Figure 10-5. DO levels measured by the Eld Inlet bottom probe 7:45 PM June 18 to 3:45 PM June 19 1999 throughout low-DO episode 4. Dissolved Oxygen levels are shown by the graph, tide heights are shown by vertical bars. (The green vertical bar is at midnight.) This episode ended when the receding tide exposed the probe to air (far right of graph). Source: Pac. Shellfish Inst. DO spreadsheet.

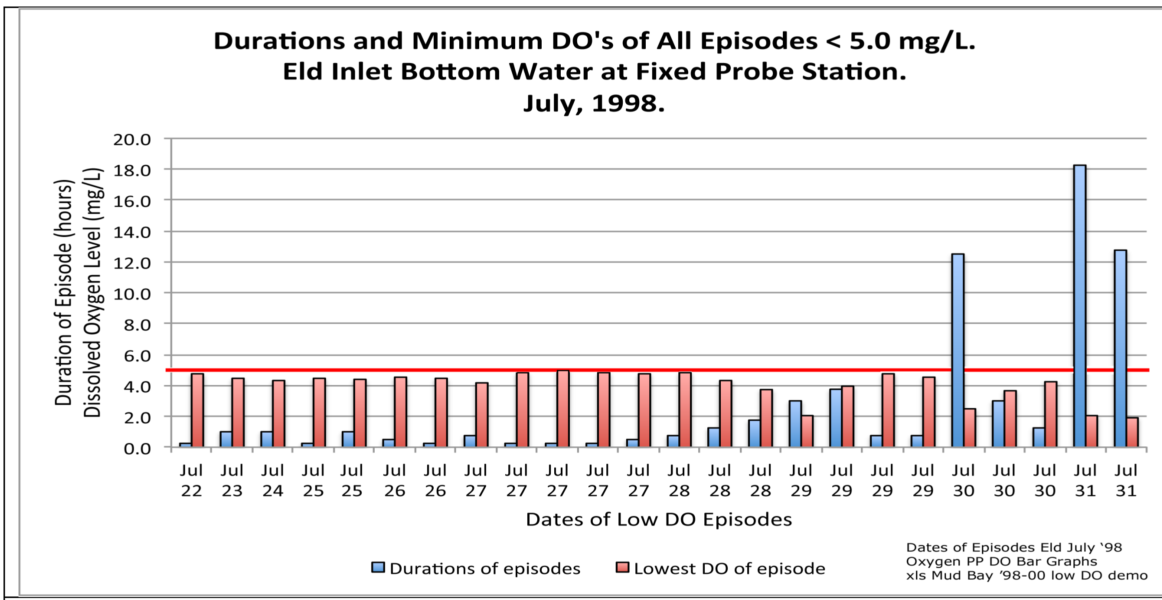


Figure 10-6. Dates of onset of low-dissolved-oxygen episodes (<5.0 mg/L) at the probe site in Eld Inlet, with their durations and lowest DO levels observed during each episode. Red line (5.0 mg/L) is the DO water quality standard in the comparable Budd Inlet Harbor area. Source: Pac. Shellfish Inst. DO spreadsheet.

The measurements made by the probe are always right at the bottom, no matter what the water depth may be. Its "last" measurement however, just before the falling tide drops below the probe's +1' level and leaves it "high and dry" is also at the surface. Similarly the probe's first measurement during a rising tide event is at the surface, when the rising water reaches its level and it begins to make measurements. It is possible to convert these bottom (and occasional surface) water measurements, made over many hours, into a "vertical profile" comparable to the more conventional measurements made by lowering a DO probe from a boat and obtaining all of the top-to-bottom readings within a few minutes.

To maintain continuity here, the method for converting the Eld probe's measurements into a "vertical profile" is described in the next-to-last (Optional) section of this chapter for interested readers. A profile so obtained is shown here in Figure 10-7 and is compared with one from Budd Inlet (station BI-5 opposite the Port dock).

The Budd Inlet measurements at site BI-5 (opposite the Port of Olympia in West Bay) shown in Fig. 10-7 are the worst (lowest) DO's observed from all of Budd Inlet in the entire year from September 10, 1996, to September 25, 1997.[2] I did not search the Eld Inlet data for the "worst case" example there; the one shown was selected for relative ease of converting the probe measurements to this format (see section 10-5).

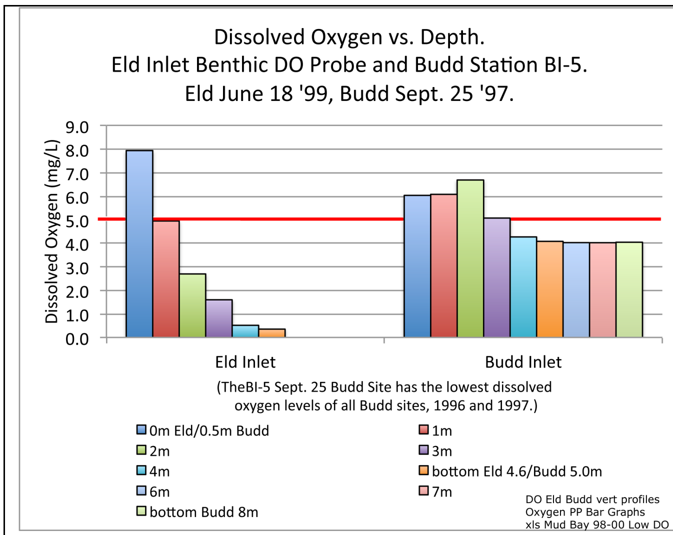


Figure 10-7. Dissolved oxygen vs depth at the Eld Inlet probe site and the Budd Inlet BISS site BI-5 (June 18 '99 and September 25 '97). The red line shows the DO standard (= 5.0 mg/L) at BI-5). Sources: Pacific Shellfish & BISS spreadsheets.

Whether we accept Eld Inlet as a modern example of a natural inlet with low DO's or not, it is clear that that inlet had far worse low DO episodes than did Budd Inlet during the late 1990's, probably more frequently and definitely beginning much earlier in each year.

10-4. Eld Inlet with "Natural" Low DO's; a Second Line of Evidence.

The modelers' interest in natural pre-modern water quality (and other objectives) led to simulations of the whole body of Puget Sound using a regional-scale model like the Budd

[2] DO measurements lower than 4.0 mg/L are shown in the BISS spreadsheet. These are all flagged as errors in the spreadsheet error pages. Lower short-lived DO's were also measured in Budd Inlet near the dam during an experimental sudden release of all of the water in Capitol Lake (July 22 – August 4 1997). Such low levels were never seen in the Inlet during normal operation of the dam.

Inlet model. Figure 10-8 shows the modern water quality standards overlaid on a grid map of Puget Sound produced by that model. (Budd and Eld Inlets are the lowermost estuaries in that Figure.) In Budd Inlet the standard is 6.0 mg/L from Boston Harbor to Priest Point Park (green on the key) and 5.0 mg/L in East and West Bays and vicinity (orange on the key). In Eld Inlet the standard is 6.0 mg/L (green; "excellent") from the entrance to the landward head of the estuary. Most Puget Sound DO levels are classified as "extraordinary" – 7.0 mg/L or higher.

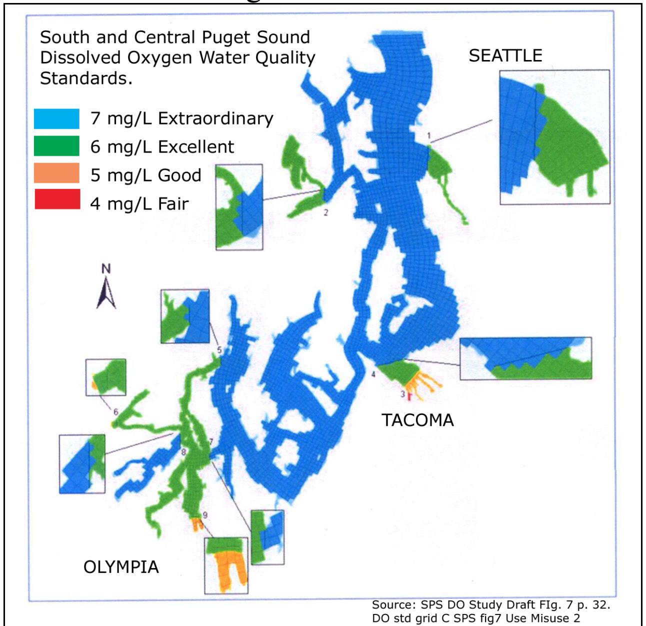


Figure 10-8. Water quality standards for all of Puget Sound from Olympia to Edmonds. Source: SPSDOS 2013 draft, p. 87.

In the next Figure (10-9) each colored grid square is a location where the standard for that location was "violated" in pre-modern "natural" Puget Sound. The size of each violation itself is not shown – the colors show instead the calculated DO level in each grid square at the time when the largest calculated violation occurred. Uncolored regions had no calculated violations during pre-modern times. Regions that remain dark blue had very small violations even though their calculated levels were below the modern standard.

<u>Almost all</u> of pre-modern "natural" Puget Sound is shown by this computer simulation to have had violations of modern water quality standards at one time or another.

In Budd Inlet, a patch of water between southern Priest Point Park and the opposite shore shows where this model found pre-modern DO's lower than the modern standard (6.0 mg/L). The rest of Budd Inlet with adjoining waters is the largest contiguous body of water in all of Puget Sound that was entirely free of DO standards violations in its pre-modern condition.

Nearby Eld Inlet, by contrast, has the lowest calculated DO's in its natural state of any region *in all of Puget Sound*.

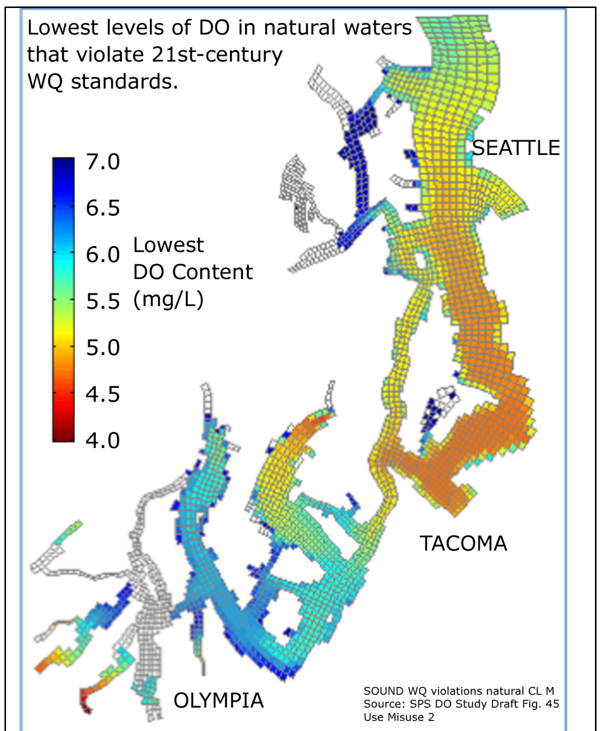


Figure 10-9. Dissolved oxygen levels at sites in pre-modern Puget Sound at the times when the model calculated their largest "violations" of modern

The modelers used these pre-modern DO levels as the standards to meet when asses sing impacts of modern human-caused- in-puts to Puget Sound that deplete oxygen.

water quality standards. Uncolored sites had no violations. Dark blue sites had excellent DO levels even though small violations occurred there. SPSDOS draft p. 87.

They found that they could not eliminate low DO levels in Eld Inlet even by eliminating 75% of all human-caused sources of oxygen depletion everywhere throughout Puget Sound from Eld Inlet to Edmonds. That supports the idea that Eld Inlet's modern low DO levels are, at least in part, of "natural" origin.[3]

10-5. Optional: How the Eld Inlet Profile was Constructed from the Probe Data.

Table 10-1 shows the data from which the tide graph and low DO levels plotted in Figure 10-7 were taken. These (Column B) are the readings made every 15 minutes (Column A) by the Eld Inlet probe between the low tide at 17:30 (5:30 PM) June 18 1999 to just past the high tide at 23:30 (11:30 PM).

A	B	C	D	E	F	G
Date/Time	DO mg/L	Tide ht (m)	Tide ht (ft)	probe depth (m)	graph depth (m)	graph DO (mg/L)
6/18/99 17:30	7.94	0.31	1.00	0.00	0.00	7.94
6/18/99 17:45	7.65	0.49	1.60	0.18		
6/18/99 18:00	2.98	0.70	2.30	0.40		
6/18/99 18:15	4.20	0.92	3.00	0.61		
6/18/99 18:30	5.02	1.16	3.80	0.85		
6/18/99 18:45	4.90	1.40	4.60	1.10	1.00	4.95
6/18/99 19:00	3.97	1.68	5.50	1.37		
6/18/99 19:15	3.91	1.98	6.50	1.68		
6/18/99 19:30	2.74	2.26	7.40	1.95		
6/18/99 19:45	2.51	2.53	8.31	2.23	2.00	2.70
6/18/99 20:00	1.87	2.81	9.21	2.50		
6/18/99 20:15	2.16	3.08	10.11	2.78		
6/18/99 20:30	1.46	3.36	11.01	3.05	3.00	1.59
6/18/99 20:45	1.93	3.60	11.81	3.29		
6/18/99 21:00	1.23	3.84	12.61	3.54		
6/18/99 21:15	0.99	4.06	13.31	3.75		
6/18/99 21:30	0.53	4.27	14.01	3.97		
6/18/99 21:45	0.47	4.42	14.51	4.12	4.00	0.51
6/18/99 22:00	0.41	4.58	15.01	4.27		
6/18/99 22:15	0.41	4.70	15.41	4.39		
6/18/99 22:30	0.41	4.79	15.71	4.48		
6/18/99 22:45	1.52	4.85	15.91	4.54		
6/18/99 23:00	0.99	4.91	16.11	4.61		
6/18/99 23:15	0.53	4.91	16.11	4.61		
6/18/99 23:30	0.35	4.91	16.11	4.61	4.61	0.35
6/18/99 23:45	0.35	4.85	15.91	4.54		
6/19/99 0:00	1.99	4.79	15.71	4.48		
6/19/99 0:15	0.53	4.73	15.51	4.42		

[3] Eld Inlet was the most resistant to improvement by reducing human impacts. The second most resistant water body was Budd Inlet. Source: SPSDOS 2013 draft.

Table 10-1. Method of obtaining a "vertical profile" of dissolved oxygen in water (as in Figure 10-7 above) using data from a probe fixed at the +1.0 ft > MLLW tide level. Column A; times of day when DO measurements were made (June 18-19 1999); Col. B; DO value measured by probe at that time; Cols. C and D tide heights in meters & feet respectively at that time; Col. E; depth of probe beneath water surface (m); Col. F; standard depths (m) for graphing; Col. G calculated DO levels at the standard depths. Col. G values calculated by interpolation between shaded depth and DO values in Cols. E and B.						

Columns A-D show observed data, E-G show my calculations.

This tidal change event began with the low tide at +1.0 ft > MLLW (Col. D, first row). That is exactly the level of the probe. The "depth below the surface" of the probe was zero at that moment (Col. E, first row). The tide height in meters at that moment (Col. C) was 0.31 m. Fifteen minutes later, the height of the tide is 0.49 m (Col. C row 2). That is (0.49 – 0.31 =) 0.18 meters above the top of the probe; the probe is now at depth 0.18 m (Col. E). Proceeding in this way the depth of the probe in meters can be calculated at each time (Col. E). To estimate DO at the standard depths of 1, 2, 3, and 4 meters, the DO values in the pairs of green-shaded cells (Col. B) were interpolated between the green-shaded depth values (which enclose the standard depth values) in the same pairs of rows. The depths and DO values used in Figure 10-7 (the Eld vertical profile) are in Columns F and G.

In most modern vertical profiles of DO (as at BI-5 in Figure 10-7) the measurements were collected by a device lowered from the surface, all within a few minutes of each other. In the Eld profile constructed as above, the deepest reading was obtained six hours after the surface reading – a drawback we just have to live with, as there is no other way to construct a vertical profile from the fixed probe data.

10-6. Where Will They Go From Here?

The widespread DO violations shown in the "natural estuary" grid map (Figure 10-2b) complicate Ecology's efforts to "prove" that "the dam" has a damaging effect on Budd Inlet's dissolved oxygen levels. The "violations" blamed on "the dam" (Fig. 10-2c), mostly calculated by comparing modern Budd Inlet with its own "natural" condition (Fig. 2-10b), are microscopic and, if anything, less widespread than they were in pre-modern times. It would better serve Ecology's purpose (and also correspond with the notion that "natural is always better") if they could contrive to show that Budd Inlet in its pre-modern condition had no DO standards violations at all.

It appears that the Department of Ecology has succeeded at this by trying yet another approach. That is to drastically reduce the number of grid squares shown in their map printouts in such a way that (they say) the Natural Budd Inlet had no water quality standards violations at all (see Fig. 10-1)!! Another "fix" is to adopt the disingenuous impossible-to-read format of Figure 10-2a, using subtle color gradations to show total dissolved oxygen instead of their standard format easy-to-read grid-map depictions of DO violations as in Figure 10-2b.[4]

If the model obstinately refuses to change its behavior in response to these latest “up-dates” and keeps showing that Capitol Lake has prevented Budd Inlet from slipping into worse water quality than prevailed in pre-modern times, I expect that Ecology will stop using grid maps entirely and will instead resort to obtuse difficult-to-track graphs like Figure 10-2a to “prove” its point. It will eventually become impossible for skeptics with limited time, no staff, and few resources to dispute their claims.

[4] I note that this latest format adoption also appears to be impossible to analyze by the Photoshop technique I used to convert Ecology’s “natural” estuary to a standard format grid map, described in detail in Chapter 5.