The Department of Ecology's Supplemental Modeling Report.
A Critical Review.

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1. BACKGROUND: ESTUARIES AND DISSOLVED OXYGEN.

1-1. Introduction.

Our Budd Inlet harbor is a dynamic moving body of marine water whose inner workings are largely out of sight and remote from our usual daily preoccupations. The obvious daily back and forth tidal flows of its waters, driven by the moon and sun, hide a second powerful flow that is not at all obvious, this one driven by the Deschutes River. It is that flow, called the "estuarine circulation," that dominates Budd Inlet's ecology and well-being. Recognizing and understanding that flow is the key to understanding – and preserving – the health of Budd Inlet and indeed all other estuaries as well.

1-2. The Estuarine Circulation; Giant Unseen Flows.

Figure 1-1 (next page) shows the giant-scale pattern of water movements typical of all temperate-latitude estuaries as applied to Puget Sound. Deep water from the Pacific Ocean enters the Strait of Juan de Fuca and ultimately Puget Sound and moves landward (Fig. 1-1a). At the same time, an enormous current flows outward at the surface.[1] The two currents mix to some extent – some deep water stirring upward and some surface water stirring downward as the waters flow over and under each other. The ocean flow stays at the bottom because the cold salty water is "heavier" (technically, "denser") than the fresh and usually warmer water from the rivers. The incoming bottom water eventually "bumps up against" incoming fresh water from a river or stream (Fig. 1-1d) and mixes with it for the return journey back to the ocean. Because of this gigantic unseen bottom-water flow from the ocean, ultimately mixing and colliding with the fresh water from rivers, Olympia Harbor waters are not fresh; their salt content is fully 85% as high as that of the ocean itself, even though the ocean is some 200 miles away from the Port.

The surface and bottom flows are created *and driven* by the fresh water entering Puget Sound from creeks and rivers. The water "piling up" at the river mouths "runs downhill" toward the ocean, dragging some of the incoming salt water with it.

The sizes of the flows are astonishing. My students and I often calculated the size of the surface flow in Budd Inlet and regularly found it to be some 20 times larger than the Deschutes River that drives it. The Department of Ecology estimates that the outgoing surface flow can be ten times larger than the Deschutes River by the time that flow passes

[1] Estuaries in desert climates have the reverse pattern – bottom flow out, surface flow in – driven by evaporation, not river flow.

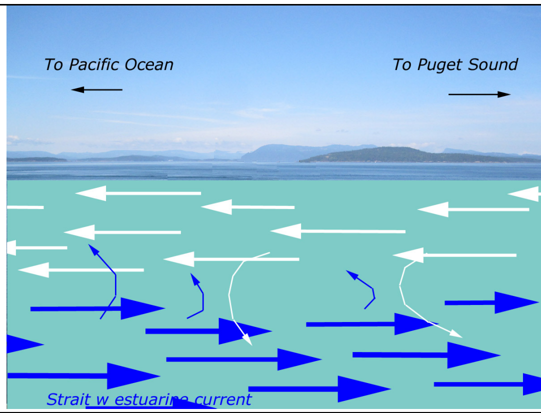

Figure 1-1a. Entry to the Strait of Juan de Fuca of deep water from the Pacific ocean, exit of surface water from regional rivers. Vertical arrows show mixing of the bottom and surface flows.

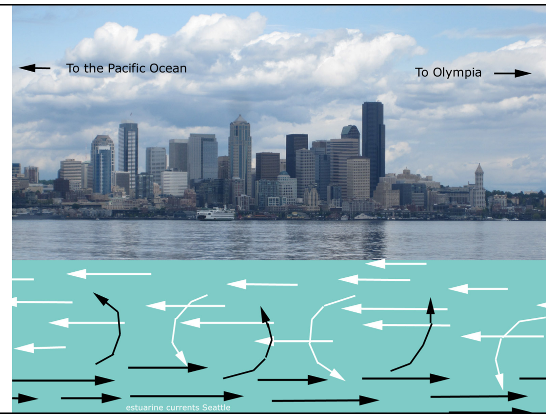

Figure 1-1b. The incoming and outgoing estuarine circulation currents with mixing as they might appear off Seattle.

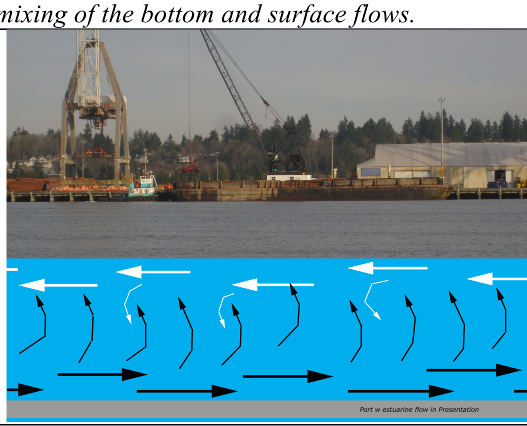

Figure 1-1c. The incoming and outgoing estuarine circulation currents as they might appear in Olympia Harbor.

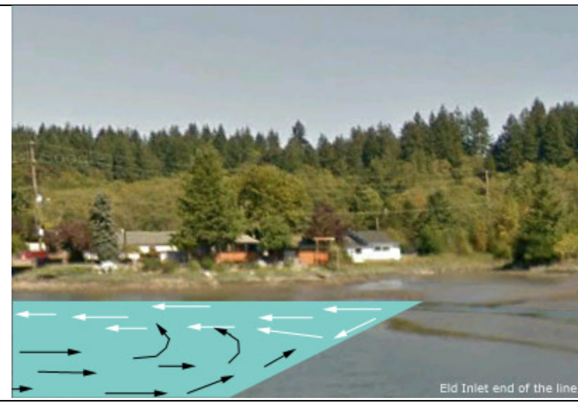

Figure 1-1d. "End of the line" for all incoming estuarine bottom currents; a collision with incoming fresh water.

FIGURE 1-1. THE ESTUARINE CIRCULATION TYPICAL OF TEMPERATE ESTUARIES.

Priest Point and 50 times larger than the river by the time it exits Budd Inlet at Boston Harbor (TMDL Appendix G p. 49). The bottom flow is very nearly as large as the surface flow.

The tides have nothing to do with this "estuarine circulation" flow pattern. Their only effect is to slosh the whole body of water inward, then outward twice a day, hiding the slower movement of the non-stop estuarine currents from easy view and detection. In fresh waters that have no tides at all (for example, Lake Erie), the same estuarine circulation pattern can be detected where rivers enter the larger water body (Herdendorf, 1990).[2]

[2] In fresh waters uncomplicated by salt content, the directions of flow of the bottom and surface currents depend upon whether the river water is colder or warmer than the lake water.

1-3. Oxygen Depletion in Estuaries.

All of the preceding is essential background for understanding oxygen depletion in estuaries.

Why focus on oxygen depletion? When we say “water quality is impaired,” we almost always mean “there are low oxygen levels in the water.” Low oxygen levels are by far the most common reason for distress among aquatic organisms, all of which need it for their respiration. “Pollution,” the presence of some chemical substance harmful to marine life in the water, is something else that may be locally very harmful, but low oxygen levels are by far more widespread than pollution. *For that reason, a computer model at the Department of Ecology – the “Budd Inlet Model” – focuses almost entirely on calculating the effects on dissolved oxygen of natural and human-sourced nutrients in the water.*

Low oxygen levels occur naturally in almost all estuaries. We can’t prevent their occurrences entirely, but we *can* prevent them from growing worse.

The next subsections address this.

1-3a. The Oxygen Story in Puget Sound.

A giant initial charge of dissolved oxygen starts toward Olympia in the bottom water entering from the Pacific Ocean (Fig. 1-1a). As the water carrying the oxygen moves landward, it is subject to a rain of organic debris from the surface that settles to the bottom, decomposes, and uses up oxygen. Much of this debris is from natural sources – living and dead phytoplankton, fecal pellets from grazing zooplankton, fragments of organisms large and small eaten by predators, leaf litter and organic material from land carried by streams, and the like. The oxygen-consuming decay is caused by bacteria. *Bacteria can use up as much oxygen as all of the more obvious large marine organisms combined*.

The normal respiration of familiar bottom-dwelling organisms -- clams, worms, crustaceans, sea cucumbers, fish, sea stars and the like –uses up oxygen. In addition, some oxygen is consumed by products of human activities – treated wastewater and phytoplankton growth caused by fertilizers, for example.

There is usually no opportunity for oxygen to be restored to the deep water. Along most of the deep dark bottom of Puget Sound, there is not enough light for plant photosynthesis to balance the respiratory/decay losses. Thus the overall effect of processes near the bottom is to deplete the bottom waters of oxygen more and more as they move farther inland.

Puget Sound is fortunate in having two locations where some of the oxygen lost from the bottom water is restored – Admiralty Inlet (between Whidbey Island and the Kitsap Peninsula) and the Tacoma Narrows. There the channel depths become shallow. Puget

Sound's large tides heave the bottom currents up to the surface where they are forced over these shallow "sills," churning and stirring the water and partially re-aerating it by contact with surface water and air before allowing it to settle back into the deep basins of the Central and South Sound (Strickland, 1983). The result is that "our" bottom water at Olympia is somewhat fresher and higher in oxygen content than it would be if the sills were absent.

Two features of every estuary work to deplete its bottom-water dissolved oxygen as that water approaches the head of the estuary. They are 1) seasonal depletion of DO in the main body of water arising from several factors and 2) the "null zone" at the head of every estuary, operating year-round. The following subsections describe these actions.

<u>1-3b. Oxygen Depletion; Seasonal Factors.</u>

Seasonal decline of oxygen in the bottom waters usually involves large sectors of estuaries. Several factors all converge to create the seasonal low DO conditions.

First, the incoming bottom current bearing replenishment oxygen slows down and shrinks in size in summer. The reason for this slowdown and shrinkage is the very reduced summer flows of the rivers that drive the whole estuarine current system. Figure 1-2 shows year-long flow records of Budd Inlet's Deschutes River at summer-long lows for 1996, 1997, 2002, and 2014, marginally lowest in September with recovery beginning in October.

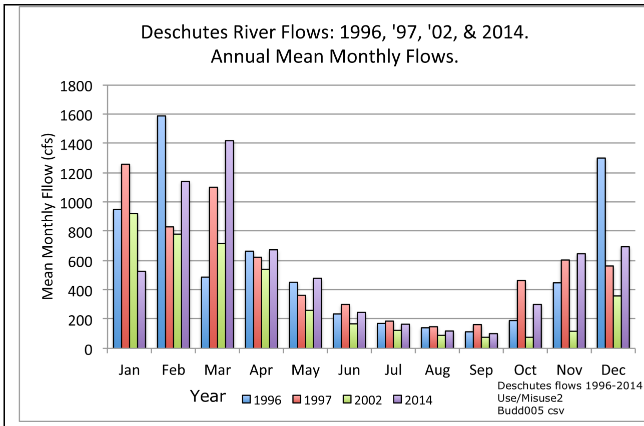

Figure 1-2. Annual flows of the Deschutes River (Olympia Washington) for 1996, 1997, 2002, and 2014. Source: USGS Water Resources site <waterdata.usgs.gov>.

The BISS (1998) study reports that "residence time" of water in Budd Inlet increases from about 8 days in winter to about 12 days in summer – a consequence of the lower flow of the river and the resulting lower flow of the estuarine bottom current.[3]

High temperatures are another driving force for oxygen depletion in summers. Warmer water "holds" less oxygen than does colder water. Worsening matters, the metabolisms of all marine organisms and bacteria "speed up" in warmer water. The organisms need and use more oxygen at a time when the water can't carry as much.

In September the sun is still high enough in the sky to drive exuberant photosynthesis by phytoplankton and algae, which creates an enormous amount of new oxygen. This, however, usually occurs in the uppermost few meters of water where sunlight is abundant.

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[3] BISS = Budd Inlet Scientific Study, conducted 1996-1997. That study is described in detail in Chapter 2.

Much of the new oxygen escapes from the water into the air, the rest is not able to easily make its way to the bottom, and the stepped up biological activity results in the sinking of more oxygen-consuming organic matter. At the bottom, where the waters are at their seasonal warmest, accelerated oxygen depletion is the result.[4] This can occur over large stretches of an estuary.

Figure 1-3 compares dissolved oxygen (DO) levels at the entrance to East Bay (Olympia Harbor) during a low-oxygen September episode and a typical "recovery" episode in October.[5] Each graph shows the DO level from the surface (leftmost bar, each group) to the bottom (rightmost bar, each group) by one-meter intervals.[6] The red line shows the DO Water Quality Standard at that site (= 5.0 mg/L). The bottom depths differ between the two graphs because of different tide stages on the dates of sampling.

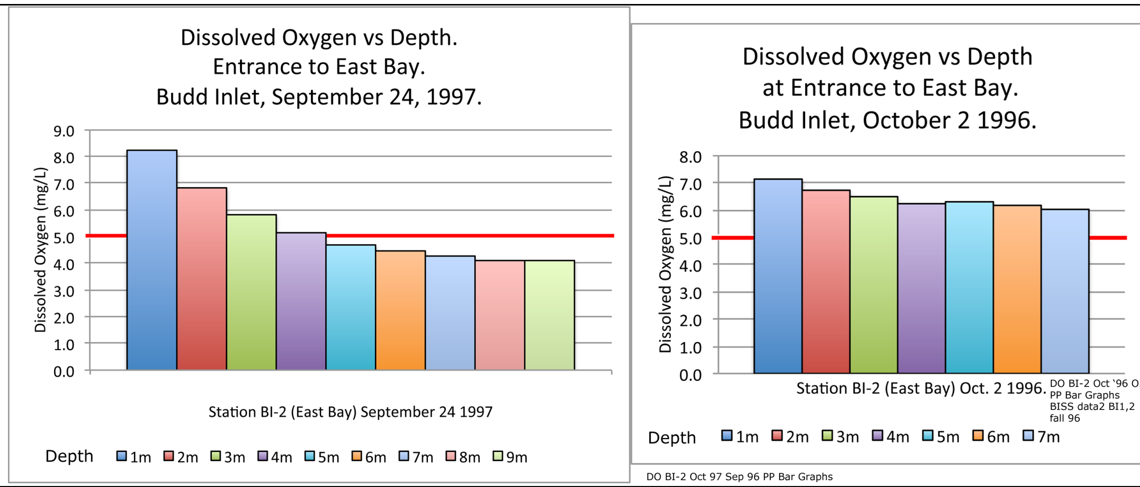


Figure 1-3. Dissolved Oxygen Levels vs. Depth for a site at the entrance to East Bay (BISS Site BI-2) during September 1997 and October 1996. Red line at 5.0 mg/L shows the DO water quality standard at that site. Source: BISS 1998 Spreadsheet.

The bottom water in September (at 9 meters) contains much less dissolved oxygen, ~ 4.0 mg/L, than in October ~ 6.0 mg/L. At the surface, the September water contains more dissolved oxygen (8.0+ mg/L) than does the October water (7.0 mg/L). Water deeper than 4 meters violates the DO Standard for this location in September; water at all depths is higher in DO than the Standard in October. These differences and changes are due mainly to stepped-up bottom circulation in October, warmer water in September, and (to

[4] There can be dramatic and not-uncommon exceptions to this rule. DO at the bottom can be higher than at the surface. See Chapter 5 where an example is analyzed in detail.

[5] The September episode was during 1997, the October episode was during 1996. Data from September 10 1996 are available and could have been used. The pattern is similar to that of Sept. 1997, however the tide was low on the 1996 date and only a few meters of water were available for sampling. The Sept. 1997 example provides a better illustration of the late summer situation in deeper water.

[6] The bar graph formats presented here are for the benefit of non-scientific readers. For aquatic ecologists, they are the equivalent of "vertical profiles" if rotated 90 degrees to the right.

a small extent) more phytoplankton photosynthesis during the longer, brighter September days.

<u>1-3c. Oxygen Depletion; The Estuarine Null Zone.</u>

The "null zone" is a low-oxygen pocket – or whole region -- that forms where the incoming bottom current collides with incoming fresh water at the head of an estuary. Two processes cooperate to form and concentrate organic carbon (and silt) particles in this zone. These are colloid formation and sediment transport, described below.

The key to understanding this situation is shown in Figure 1-4.

Between the outgoing and incoming estuarine circulation currents is a depth at which there is no net horizontal motion (Fig. 1-4a). There, no water moves landward or seaward. (Vertical motions of water through this interface are routine and common.) At the end of the estuary where the incoming salt water finally collides "head on," so to speak, with the incoming fresh water stream, the bottom current stops and turns upward. Here the "depth of no net horizontal motion" touches bottom. The point where the last of the bottom current stops and turns upward is the "null zone" (Fig. 1-4b).

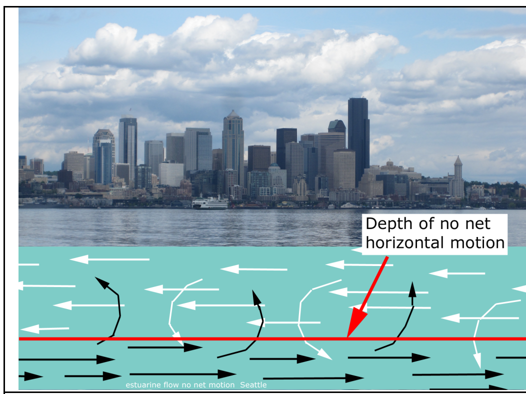


Figure 1-4a. Depth of no net horizontal motion at the interface between the incoming and outgoing estuarine circulation currents. (Extends the entire length of the estuary.)

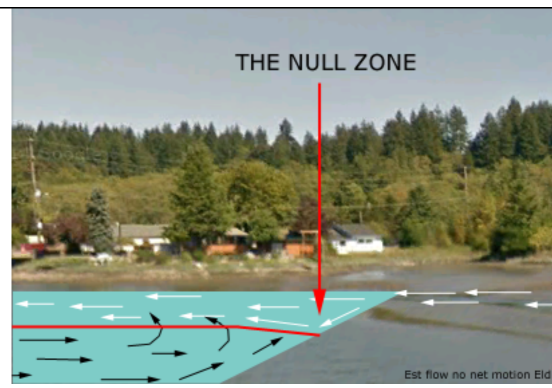


Figure 1-4b. The Null Zone: where the depth of no net horizontal motion touches the bottom at the head of the estuary.

At the landward end of the estuary, the null zone doesn't stay in the same place for long. Each flooding tide moves it landward, then the next ebbing tide moves it back seaward. The null zone effect on oxygen is distributed over the whole area where it sweeps back and forth.

Two processes concentrate organic carbon particles in the null zone. First, the collision of fresh- and salt-waters prompts chemical and physical changes in organic molecules and tiny particles carried both by the stream and the marine bottom current. These changes cause the particles to "clump," forming larger particles ("colloids") that become concentrated in the area where they form. There they decompose, using up dissolved oxygen. Second, where the horizontal movement of bottom water stops (where the depth of no net horizontal motion touches bottom, Fig. 1-4b), small sediment and carbonaceous particles being swept along the bottom settle and accumulate. Both processes cause particles to accumulate in the null zone.

As a result of concentration of suspended particles there, the null zone can be found by measuring water turbidity along the length of an estuary. A marked "turbidity maximum" (Dyer, 1986) occurs where the zone is located.

Mann (1982, p. 231) gives an excellent account of both colloid formation and bottom sediment transport processes around the null zone, using Belgium's Scheldt River Estuary as an example.[7] The estuary has huge tides at its entrance (range ~ 6.5 meters) and is located in low flat country. There the turbidity maximum is centered at about 80 kilometers inland and the sweep of the tides moves it back and forth perhaps 20 km upstream and downstream in each direction from that central location.

Dyer's (1986) description of null zone phenomena focuses on the physical processes of sediment transport in estuaries, with an extended discussion of the formation and movements of the turbidity maximum.

Ecology's computer simulations focus on the effects of nitrogen nutrients on Budd Inlet. *No mention of the null zone is ever made*. The importance of this never-mentioned feature of estuaries is this; the bottom currents in an accurate hydrodynamic model (which the Budd Inlet model is) would create a turbidity maximum at the head of an estuary even if the model's creators didn't explicitly design it with null zones in mind.

Colloid formation is another matter. That is a special physical-chemical process unique to the heads of estuaries that would need to be specifically built into the model by its creators. I don't know whether the Aura Nova consultants who created the model included that or not. But the sediment transport feature of a hydrodynamic model would be enough, by itself, to create a null zone turbidity maximum.

These carbon-concentrating processes with their oxygen-depletion capabilities are totally independent of the presence or absence of nitrogen nutrients. Some of the organic carbon accumulating at the head of each estuary arrives in part from particles of land origin – leaf litter and the like. Unless one watches and tests for its effects, low oxygen seemingly created by nitrogen-fed marine plant growth and decay may actually be due to a null zone effect.

1-4. Reading the Oxygen Record.

Each year observers from the Department of Ecology measure the oxygen concentrations at depths ranging from the water surface to the bottom at locations (= "stations") all

[7] Mann does not use the term "null zone." Dyer uses the term "null point" for the location where the depth of no net motion touches bottom. I recall that "null zone" was widely used when I began teaching in the 1970's but it seems to have fallen out of common usage.

around South Puget Sound. There are two stations in Budd Inlet; one opposite the Port Dock, the other near the Olympia Shoal (Figure 1-5).

Figure 1-5. Stations sampled yearly for measurements of dissolved oxygen and other water properties by the Department of Ecology. Source: Ecology Ambient Monitoring Program 2018.

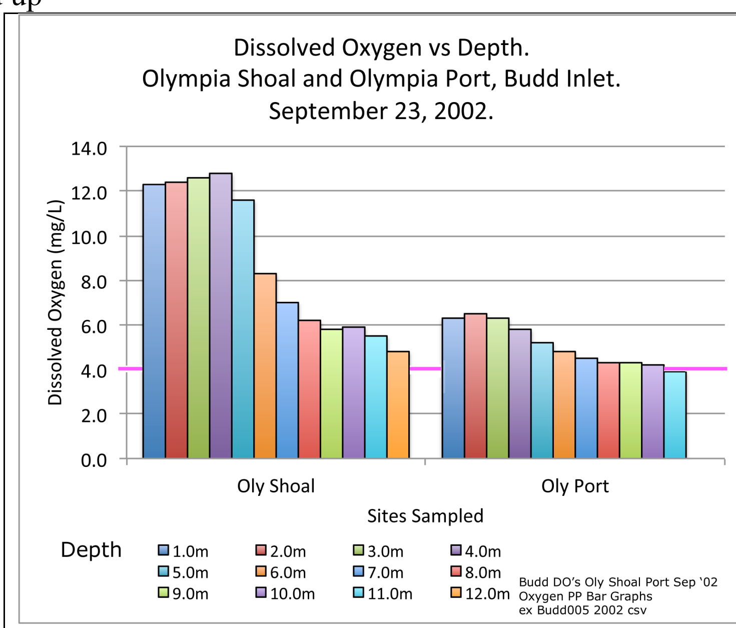
On September 23, year 2002, the measurements opposite the Port dock showed many low dissolved oxygen (DO) levels. These and readings made on the same day at the Olympia Shoal station are shown in Figure 1-6. At the Oly Shoal, surface and bottom DO levels were about 12 and 5 mg/L; at the Port station they were lower at about 6 and 4 mg/L, respectively. (The leftmost bar shows the surface reading, the rightmost bar shows the bottom reading respectively in each group.)

At first glance, the much lower DO's across from the Port suggest that something in the water opposite is aggressively using up oxygen -- some pollutant, perhaps from Olympia? Or something from Capitol Lake?

NO. There is a different reason for the low DO's at the Port. A standard way of finding that reason is shown in the following.

1-4a. DO Saturation: Key to Understanding Water Quality.

When surface water has "soaked up" as much oxygen from the air as it can hold, the water is said to be "100% saturated." Its oxygen content will remain exactly at that 100% level for as long as it is in contact with the air and no other process (plant photosynthesis or animal/bacteria respiration) acts to change it. The amount of oxygen that water can hold at its saturation level is greater if the water is colder and less if the water is salty. Thus fresh water at saturation will always hold more oxygen than O2-saturated salt water at the



same temperature. Aside from that easy rule, one must always calculate water's saturation level from tables or computer programs, using the measured temperature and salinity of the water.[8]

Figure 1-6. Dissolved Oxygen vs. Depth at Ecology stations BUDD 005 and BUDD 002 (see Fig. 1-5.) Source: Ecology Ambient Monitoring Program, 2018.

Left standing in air with no changes in temperature or salinity, the concentration of oxygen in the water will remain unchanged at the saturation level. If the growth of plants in the water creates new oxygen, the DO level will rise *above* the saturation level. That situation will last only so long as the plants continue to add oxygen. The extra oxygen immediately begins to escape from the water by diffusing into the air. The plants can add new oxygen faster than this diffusive escape can remove it, but once their growth stops, the water spontaneously returns to its 100% saturation level. The escape of the excess oxygen and return to equilibrium (100% saturation) is usually complete by about two or three days after plant growth stops.

In the opposite direction, consumption of oxygen in the surface water by some means or other can lower its oxygen content below the 100% level. In such cases, oxygen diffuses back into the water from the air and restores the 100% level as soon as the consumptive processes stop.

Water with a DO level measured at higher than 100% is said to be "supersaturated." That is a sure sign that plants and/or phytoplankton have been growing profusely and liberating excess oxygen. If the DO level is measured at lower than 100%, it is said to be "undersaturated." That is a sign that something – usually bacteria and aquatic organisms – is removing oxygen from the water by respiration. Plant growth can only take place at the sunlit surface – respiration is usually most powerful in the dark water at the bottom where respiring organisms are concentrated. Because the bottom water has no contact with the air, undersaturation remains unchanged there for long periods of time.

The "pain" of this long explanation gives us the "gain" of being able to interpret dissolved oxygen patterns like those in Figure 1-6 above. At each of the two stations shown, the highest DO levels are at the surface (or just beneath it at shallow sunlit depths). That is because of phytoplankton growth there. The lowest DO levels are at the bottom, where respiring bacteria and marine organisms are concentrated. That's as expected.[9] But those Figures don't show us the 100% DO levels at those stations. The percent saturation levels are shown in Figure 1-7 below.

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[8] An example of using a computer calculation (on line at a USGS website) is shown in Chapter 9. Another method (for fresh water only) is also shown there.

[9] In fact high DO at the surface, low DO at the bottom is the standard pattern to always be expected in aquatic DO measurements. Watch for it throughout this entire document. There is just one instance (described in Chapter 5) where the pattern is completely reversed … for reasons explained in that example.

1-4b. Bottom Water Rising in Olympia Harbor.

Figure 1-7 shows that *the surface water opposite the Olympia Port dock is undersaturated in dissolved oxygen*. At the very surface (leftmost bar, Oly Port figure) the water contains only about 80% as much oxygen as it would normally acquire by standing in contact with air (that is, 100% saturation shown by the blue line). *That should not be the case*; surface water in summers is supersaturated almost everywhere thanks to the photosynthesis of phytoplankton cells. In fact, *undersaturation of surface water is conclusive evidence that bottom water is rising to the surface at that location*.

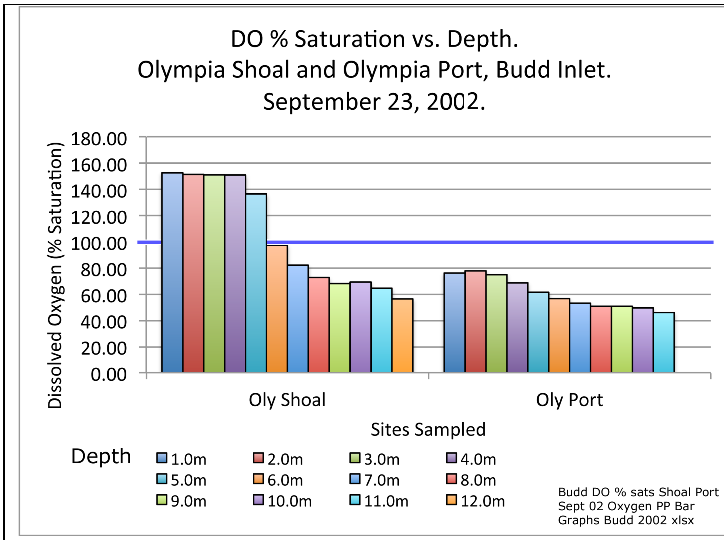

Figure 1-7. Percent oxygen saturation of Budd Inlet waters at two locations, September 23 2002. Blue line shows the 100% saturation level. DO data from Ecology Ambient Monitoring Program, % saturations calculated from USGS DOTABLES (on line) tool.

Figure 1-1c shows this rising water process in action. As the giant bottom current from Puget Sound beyond Budd Inlet enters the Port area, it brings with it the low DO levels that it acquired during its long passage along the bottom. That bottom water is undersaturated. As it continually mixes upward into the outgoing surface current, and especially when it collides with the incoming fresh water at the end of the estuary and is forced to the surface, it lowers the average DO level at the surface.

What about the situation at the Oly Shoal sample site? At that location (north of the Port and "downstream" from it in the outgoing surface flow), the surface water is supersaturated with oxygen. Indeed the surface at that site (leftmost bar) is at about 150% saturation, containing half again as much oxygen as the water would acquire by itself by simply standing in contact with the air.

The extra oxygen at the Oly Shoal surface was added by phytoplankton growth. The plant cells are living in water that rose to the surface, undersaturated in DO, a few days earlier at the Port site and beyond. In the time it has taken for that surface water to drift out to the Oly Shoal, photosynthesis (with some initial uptake of oxygen from the air) has driven the surface oxygen to supersaturation levels.

Someone taking oxygen measurements at the Oly Port station would immediately see that DO levels were very low there and might conclude that those low DO's are caused by something in the water right there at the Port. That would be mistaken. The low DO's were *mostly* already there in water that was carried into the Port area in the bottom current from outside Budd Inlet.[10]

1-5. What's Driving Low September Dissolved Oxygen Levels in Budd Inlet?

The answer to this question is "nitrogen nutrients." In the water, they are taken up by phytoplankton cells, which use them for growth and multiplication. The new plant matter sinks and decays. As mentioned above, all new oxygen is created by plants at the sunlit surface of the water, where most of it escapes into the air as the water returns to its saturation level. Decay is at the bottom, where oxygen is consumed and depleted. The vast flush of new oxygen that the nutrients make possible doesn't help the estuary ecosystem very much, but the decay that follows that flush – the "hangover after the party," so to speak – definitely stresses it. Return of larger river flows in fall steps up the inward-moving estuarine bottom current and brings faster flushing and more oxygen to the estuary bottom. Later during the fall, a giant "turnover" of the whole body of Puget Sound water takes place that completely obliterates all of the oxygen depletion accrued during the year at all depths. This annual "turnover" (described in Chapter 8) essentially re-sets the estuary ecosystem back to its starting point, to begin a new year of ecological action.

What about the sizes of the nutrient nitrogen loads entering Budd Inlet every year? No understanding of the Inlet's situation can be complete without appreciating the volumes of those loads, shown in Figure 1-8.

Nitrogen enters Budd Inlet from the four sources shown in Figure 1-8. From left to right, they are 1) the Deschutes River watershed, 2) all of the rest of the small creeks around the shores, 3) the LOTT

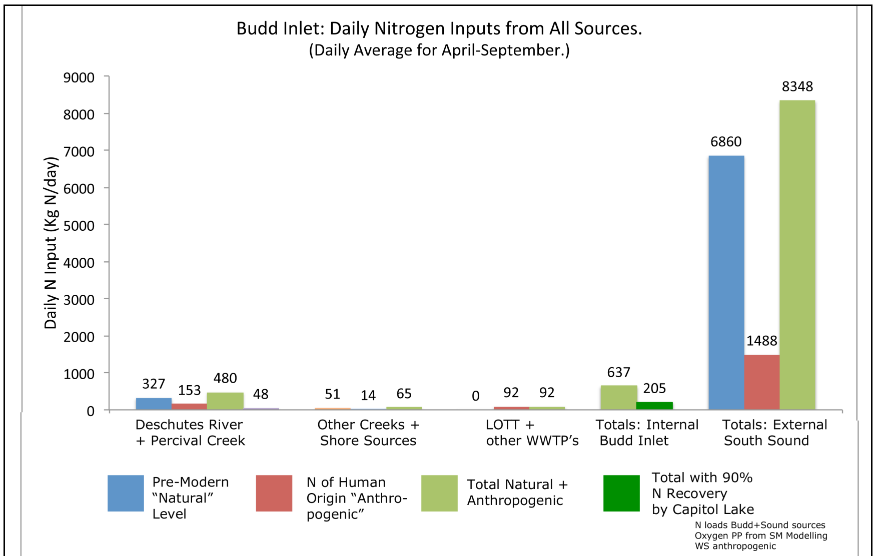

Figure 1-8. Nutrient nitrogen inputs to Budd Inlet from all sources, internal and external. Sources. From left to right, sources are 1) Deschutes River watershed; 2) other small creeks around Budd Inlet; 3) the LOTT WWTP, totals of these three "internal" sources, and 4) South Puget Sound outside Budd Inlet (= "external" sources). [For visualization, I have included Capitol Lake's effect (removal of about 90% of incoming nitrate from the Deschutes River water), not mentioned by Ecology. CH2M-Hill, 1978.] This important Figure is described in detail in Chapter 6, this Review.

[10] "... *mostly* already there …" As the bottom water enters the Inlet, its oxygen concentration continues to drop due to respiration at the bottom and decay of sinking phytoplankton created in the surface rush of nutrient-fueled growth. Between the Oly Shoal and Port stations (about half of the length of Budd Inlet) the bottom DO drops by about 1 mg/L, a result of processes inside Budd Inlet.

wastewater treatment plant, and 4) Puget Sound outside the Budd Inlet entrance (the "external" source). Blue bars show the estimated sizes of the "natural" nitrogen inputs that existed before human activity began influencing Budd Inlet, red bars show the sizes of loads created by human activities, and the pale green bars show the totals.

The dominant feature by far of this graph is the gigantic size of the external nitrogen inputs. That daily nitrogen load – fully 8,348 kg N/day -- drives the Budd Inlet ecosystem. Within Budd Inlet the Deschutes River would contribute the most nitrogen – 480 kg/day -- if it were not filtered through Capitol Lake, which captures and holds almost 90% of that load. The LOTT plant, a top-of-the-line treatment facility, adds about 92 kg/day. The tiny loads carried by the "other small creeks" are inconsequential except for one glaring exception. That is Watershed Park's Moxlie Creek, with one of the highest nutrient nitrogen concentrations of any stream entering all of South Puget Sound, draining into the sluggish semi-isolated cul-de-sac of East Bay.

This perspective informs us for a final look at the whole Budd Inlet situation as portrayed by the Department of Ecology.

1-6. What the Budd Inlet Water Quality Controversy is All About.

One or two times a year in September, the DO levels in East Bay drop below the water quality standard there (5.0 mg DO/L). Those low oxygen episodes last for a few days, then recover (usually by the end of the month). East Bay is the "epicenter" – the "ground zero" of seasonal low DO levels in Budd Inlet. Low September DO levels occur elsewhere around Budd Inlet, always south of Priest Point. For the rest of the year, with occasional occurrences in August, DO levels below the standards are largely rare or nonexistent.[11]

Ecology's computer model personnel blame the yearly low DO episodes in East Bay on Capitol Lake. Their aggressive claim is analyzed in Chapter 6. My view is that they have been misled by the behavior of the estuarine bottom current carrying the huge external load seen in Figure 1-8. By the time that current reaches Priest Point, it has been diminished (by upward mixing into the outgoing surface water) to about 20% of its incoming size. That 20% carries 3.5 times as much nutrient nitrogen as would the Deschutes River with no dam and about 35 times as much nitrogen as does the Deschutes River water after passage through Capitol Lake. By the time that incoming bottom current reaches the dam site, turns upward, joins the out-flowing Capitol Lake water and returns toward East Bay, only about 3% of its total nitrogen load is from the Lake – the rest is from outside Budd Inlet. Most DO depletion, wherever it takes place, is caused by the external load – not the Capitol Lake dam.

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[11] DO levels lower than the standards occur throughout much of central Budd Inlet in October, then recover in November as a result of the "turnover" process mentioned in the preceding section. That is beyond the "view" of Ecology's computer model (which stops in mid-September) and occurs at a time when the low DO's are not a threat to the ecosystem. (See Chapter 8 for a description of this.)

East Bay is impacted by many factors that converge to reduce its dissolved oxygen levels. These are described in detail in Chapter 6.

Regarding Ecology's claims, it strains credulity to accept that some disturbance – nitrogen-driven or hydrodynamic -- that starts at the end of West Bay radiates all the way around the Port Peninsula and far up the dead-end East Bay beyond the Swan Town Marina to finally focus its worst oxygen depletion effect on that isolated backwater.

Figure 1-9 shows Budd Inlet's lowest-DO-levels-of-the-year as calculated by Ecology's computer model for a time before human activities began to change DO levels. In other words, Figure 1-9 shows the lowest DO's occurring in the "natural" (pre-modern) Inlet. The most obvious feature is the DO "hot spot" in East Bay – there long before Capitol Lake and the dam existed. The "critical cell" that Ecology focuses on is the darkest red spot on the map, near the head of East Bay. Many possible explanations for these "violations" of modern standards – the natural nitrogen loads from the external source and Moxlie Creek, and the "null zone effect" – existed then. Ecology's model operators are attempting to shift all of the blame for that pre-modern situation to modern activities.

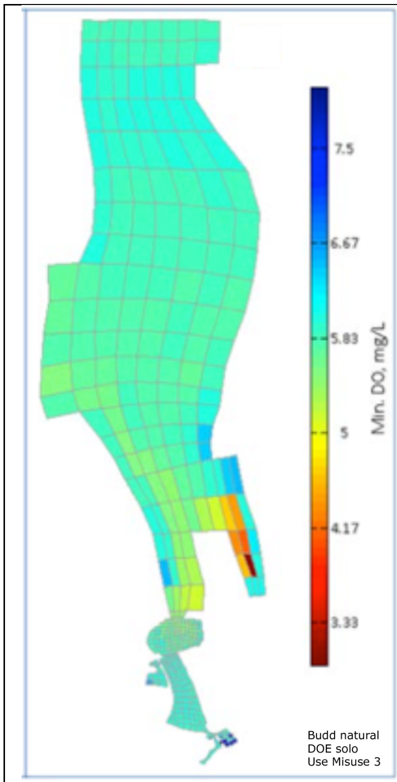

Figure 1-9. Violations of modern dissolved oxygen standards in pre-modern Budd Inlet as calculated by Ecology's computer model. (In this figure, the Capitol Lake basin is tidal estuarine water.) Source: SM Report Fig. 7b, p. 32.

Despite the fact that Ecology focuses its theories on East Bay, the agency has never (to my knowledge) made dissolved oxygen measurements there. The last observations of DO levels there were (to my knowledge) made by the Budd Inlet Scientific Study team in 1996-97 (see Chapter 2 for a description of this outstanding study). That study shows September low DO's in East Bay and elsewhere (mainly West Bay) on some days, high DO's in those same places on other September days, and no significant low DO's anywhere else during the other eleven months of the year.[12]

So what is the controversy about? Based on computer model predictions and *only* computer model predictions, Ecology is trying to persuade the public that we must remove Capitol Lake and replace it with a tidal estuary. The "benefit," they claim, would be removal of the once-a-year low-DO "hot spot" in East Bay, and lesser low DO's elsewhere.

[12] As mentioned in a previous footnote, low DO's develop at all depths in central and outer Budd Inlet in late fall as a result of surface cooling. These abruptly vanish in November. These low DO's occur long after the growing season and are not regarded as "significant." See Chapter 8 for a detailed description of this process.

As I report in the following Chapters, I think they are very mistaken for the reasons I mention. Removal of Capitol Lake would damage, not help, Budd Inlet. It would also cost 400 million dollars (Curry, pers. comm. 2018) and would replace a landscape feature much beloved by the public with malodorous tide flats.

Thanks for reading this! Understanding the features of estuaries is key to understanding the Lake/estuary controversy. And if you hear a speaker mention “low DO’s” in Budd Inlet as a reason for removing Capitol Lake, you might ask “Is the surface water of the Inlet undersaturated with oxygen?” If the speaker doesn’t know what you’re talking about … then he or she is simply repeating talking points provided by estuary promoters.