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DEPARTMENT OF ECOLOGY
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MEMORANDUM
June 22, 1983

To: Frank Monahan

From: John Bernhardt and Bill Yake

Subject: LOTT Phase II Receiving Water Considerations

We have reviewed information on water quality in Budd Inlet emphasizing those areas which relate most closely to LOTT Phase II. Our review should be regarded as "preliminary" since we were not able to consider all of the literature in detail due to time constraints. Even considering this, we believe the water quality issues of principal concern are covered.

Five areas of concern were evaluated, including: (1) water quality index; (2) dilution and dispersion; (3) toxic pollutants; (4) aquatic biota; and (5) nutrients/algae/dissolved oxygen. The water quality index compares the quality of Budd Inlet waters with other waters in the state. This is one basis for Departmental priorities. Dilution and dispersion are basic considerations relating to the ability of the inlet to assimilate waste loads. Toxic pollutants including heavy metals and organic contaminants have received considerable attention in Puget Sound during recent years. The aquatic biota category addresses the important concern of fishkills and disease. Finally, the complex issue of nutrients/algae/dissolved oxygen is addressed because of its special importance to Budd Inlet which periodically experiences algal blooms and low dissolved oxygen conditions.

As previously noted, these five areas by no means represent all possible water quality considerations. Collectively they provide a good indication of existing environmental conditions and help identify some of the more important water quality issues to be addressed if the inlet is considered for greater waste loads in the future.

The information reviewed reflects conditions prior to the new LOTT wastewater treatment plant coming on line. A post-upgrade facility inspection accompanied by a receiving water survey would be needed to fully evaluate existing conditions. Only the Water Quality Index cited above should be significantly influenced by the new plant. The primary

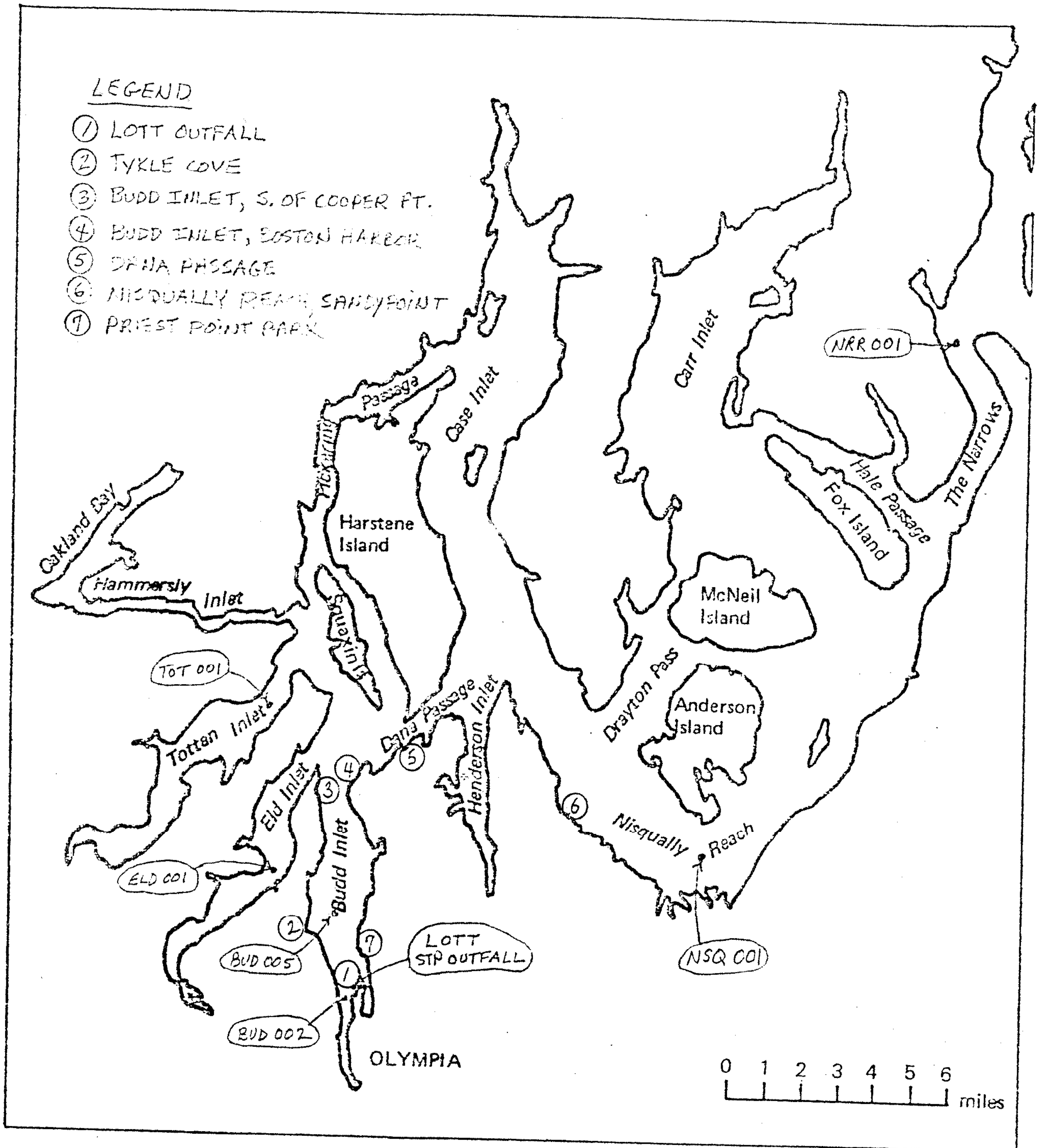


Figure I Area Map of the Southern Sound and WDOE Ambient monitoring stations.

Source: Dexter, et al. (1981)

Table 1. Water Quality Index ratings for Washington marine waters evaluated during 1982.

Area Description	Overall Index
*Inner Budd Inlet	44.1
Port Gardner and Everett Harbor	43.7
Duwamish Waterway & Lower Green/Duwamish River	42.6
Inner Commencement Bay & Lower Puyallup River	38.9
Inner Grays Harbor	38.3
Commencement Bay	25.2
Kitsap Peninsula and Inlets	15.5
Elliott Bay	14.9
Inner Bellingham Bay	13.9
*Outer Budd Inlet	9.1
Saratoga Passage	7.7
Oakland Bay	6.9
Port Angeles Harbor	6.2
Drayton Harbor	6.0
Grays Harbor	5.8
Possession Sound	5.8
Skagit and Similk Bays	5.7
Bellingham Bay	5.6
Eld Inlet	5.5
Samish Bay	5.4
Willapa Bay	5.4
Padilla Bay	5.3
Fidalgo Bay	5.2
Carr Inlet	5.0
Totten Inlet	4.9
Tacoma Narrows	4.6
Case Inlet	4.5
North Puget Sound	4.5
Pickering Passage	4.5
Port Susan	4.3
Sequim Bay	4.0
San Juan Islands	3.8
Port Townsend Harbor	3.3

*The two Budd Inlet stations.

reason that Budd Inlet has a high index rating is fecal coliform counts in the lower embayment have historically been quite high. The plant should have helped decrease coliform levels in the inlet, but the extent to which this might have occurred will not be known until a study is performed.

A discussion of each of the five areas investigated follows. For reference, Budd Inlet and adjoining waters are shown in Figure 1.

1. Water Quality Index (WQI)

The WQI "rates" the quality of marine and freshwaters throughout the state. The rating system is primarily based on data routinely collected from the statewide WDOE routine water quality monitoring network, although other sources such as intensive studies also are considered. The network includes more than 100 stations. Basically, data for ten indicators of environmental quality are compared against established water quality standards and criteria:

a. temperature
b. dissolved oxygen
c. pH
d. bacteria (fecal coliform)
e. trophic (nutrients)
f. aesthetics (mainly turbidity)
g. suspended solids
h. radioactivity
i. organic toxicity
j. ammonia toxicity

For each indicator, an abstract number is generated based on an assessment of the ambient data for recent years. A data base of five years or more is preferred per station. WQI scores of 0-20 meet the federal goals for water quality; scores in the 20-60 range are considered marginal; and values exceeding 60 are unacceptable.

It is important to note that the WQI is the only one means to rate water quality and does not provide all of the answers. It does not address some specific conventional pollutants or toxics nor, in many cases, does it reflect localized problems not picked up by the ambient stations. The WQI is one tool which must be considered along with other available information in evaluating the condition of a particular body of water.

The most recent WQI analysis performed for Budd Inlet (Monn, 1982) shows the following:

Ambient Station Location	Parameter										Overall Index Rating
	Temp.	Oxygen	pH	Bact.	Troph.	Aesth.	Susp. Solids	Rad.	Org. Tox.	Ammonia Ammonia	
Inner Budd Inlet	9.4	37.2	4.6	55.9	--	3.0	--	--	--	3.5	44.1
Outer Budd Inlet	9.8	13.8	9.2	18.3	--	1.7	--	--	--	3.5	9.1

The flushing time is the number of tide cycles required for the inlet to completely replace itself. Time in days is approximately one-half the time shown. The same calculation for all of Puget Sound yields 25.3 cycles (Duxbury, et al., 1972). Thus, flushing time for Budd Inlet is about 10 times faster than for all of Puget Sound.

Flushing time estimates are of only limited value and must be used cautiously because a number of key considerations are not addressed: (1) Flushing efficiency. Friebertshauer and Duxbury (1972) define flushing efficiency as the ability of a basin to completely flush itself with new water. Flushing time calculations do not account for the fact that some of the water flushed out may return with the next tide. Flushing efficiency may differ substantially by location within an embayment. This is an important consideration in the case of Budd Inlet where a number of alternate sites for wastewater disposal may be evaluated. (2) Wind and barometric pressure. Northerly winds which occasionally prevail during summer, may hold surface waters in the inlet, decreasing flushing time (Oclay, 1959). (3) Freshwater inflow. Careful consideration must be given to the Deschutes River which can, at times, be a dominant force, especially in the lower inlet. Also, at times there is no inflow when Capitol Lake is being filled after a draw-down.

Devitt (1974) attempted to evaluate dilution and dispersion of wastewaters discharged from the Olympia wastewater treatment plant. Dye was added to the effluent three times during outgoing tide and tracked for several hours by airplane. An easily defined pattern of movement was not evident. Some of the dye drifted outward toward Olympia Shoal, some drifted to the west, while another patch lingered near shore in front of the KGY radio station. Unfortunately, the study was curtailed shortly after the tide began coming in. An aerial photography plane in the vicinity later in the day on a separate mission obtained several photographs which showed substantial amounts of dye drifting back past the outfall toward the head-end of the inlet.

Prior to the upgrade of the Olympia wastewater treatment plant, KCM (1975) evaluated 13 potential discharge sites. An abbreviated receiving water study was included. The physical model of Puget Sound at the Department of Oceanography, University of Washington, was used to obtain a quantitative estimate of dispersal characteristics for five of the sites:

a. Budd Inlet, near Tykle Cove;

b. Budd Inlet, off Boston Harbor;

c. Budd Inlet, south of Cooper Point;

d. Dana Passage; and

e. Nisqually Reach off Sand Point

The overall rating for inner Budd Inlet is higher than the average of the six individual ratings where data were available because penalty points are added if the established criteria for a particular parameter are exceeded (Singleton, 1981). This was the case for bacteria (55.9) and dissolved oxygen (37.2). These data show that inner Budd Inlet is rated marginal.

Budd Inlet is compared with other marine waters in the state in Table 1. The inner inlet received the highest overall rating (worst score) of all the areas evaluated. Waters with similar ratings include Port Gardner and inner Everett Harbor, Duwamish Waterway and Lower Green/Duwamish River, inner Commencement Bay and lower Puyallup River, and inner Grays Harbor. The WQI improves considerably with the outer inlet, but is still higher than most marine waters of the state.

2. Dilution and Dispersion

Limited information is available on tidal flushing and circulation patterns in Budd Inlet. Similarly, other than some general observations, little is known about the ability of this embayment to assimilate waste loads generated by man. This is particularly true when specific discharge sites are considered for disposing of treated wastewaters. A brief discussion of existing information on dilution and dispersion follows.

Oclay (1959) calculated that nearby Oakland Bay had a flushing "half-life" of about eight days. He was not able to calculate flushing for Budd Inlet, but believed that the rate was much faster because:

a. The inlet lacks an entrance sill;

b. The inlet has a wide mouth which opens to a well-mixed tidal channel; and

c. The lack of turbulent mixing allows surface waters to escape from the inlet.

Three authors have calculated the flushing time for Budd Inlet using the ratio of basin volume to intertidal volume:

McLellan (1954)	Collias (1970)	Kruger (1979)
3.3	2.8	3.1

The data for 1972 shows that the water flowing into Budd Inlet primarily moves down the west side of the bay with minimal vertical and horizontal mixing. Then considerable mixing of near-surface incoming and outgoing waters occur between Butler Cove and Priest Point. A limited amount of the mid-depth to bottom water continues to flow south from Butler Cove along the west side of Olympia Harbor rising to the surface as the bay becomes shallow.

During the summer the water entering Budd Inlet generally has high DO and salinity levels with low BOD, low phytoplankton abundance and low turbidity. As the water progresses southward through the bay the BOD, DO, phytoplankton abundance, and turbidity of the near-surface water (top 10-foot layer) increased steadily until a peak is reached in Butler Cove. The bottom water remains relatively unchanged until it rises to the surface at the south end of Olympia Harbor. When the fresh water flow from Capitol Lake is low the near-surface water at the south end of the ship channel is similar in BOD, phytoplankton density, and turbidity to the water of Butler Cove from the mid-depth to the bottom. Also, the DO concentration of the surface water at the south end of the harbor are much lower than for most of Budd Inlet in summer.

As the water turns to flow northward in Olympia Harbor, the BOD and turbidity levels increase partly due to the influence of the domestic effluent. Sometimes the city wastewater increases the ammonia and phosphate concentrations greatly at the surface for a distance of up to 0.4 mile north of the sewer outfall. Near Priest Point accelerated mixing of waters moving north and south increases the DO, phytoplankton, and salinity levels of the outgoing water. The BOD and turbidity values change little because the surface waters moving from Butler Cove and Olympia Harbor have similar values for these properties.

The DO and phytoplankton values north of Priest Point were lower and the BOD and turbidity values were higher along the east side than the west side in summer. During the 1972 study period the average DO concentration of the bottom water of inner Olympia Harbor was about 6.0 mg/l while it was near 5.0 mg/l north of Priest Point on the east side as far as Gull Harbor. The DO values at the surface were much higher than at the bottom on that side."

It is clear from the foregoing studies that circulation patterns in Budd Inlet are only generally understood. Little is known about

Basically, the model was set to coincide with a specific time of year, April 6-12 neap tides, then effluent inflow was simulated by adding dye at a prescribed rate. Dye movement was visually observed. Dana Passage was found to be the best site with Nisqually second, Boston Harbor third, south of Cooper Point fourth, and south of Tykle Cove fifth. There is some question as to whether this Puget Sound model can be carried to the limits used. It is small (1:40,000 horizontal and 1:1,152 vertical scales) and probably of limited value for evaluating specific discharge sites in individual embayments.

Float (drogue) studies were performed in the field at three locations: Tykle Cove in Budd Inlet; Olympia entrance channel in Budd Inlet (near existing outfall); and at Dogfish Bight on the Nisqually Reach. For the effort, drift drogues were set at the surface and depths of 10, 20, and 30 feet and followed for one to six hours, mainly during outgoing tide. The findings were:

a. Currents were considered weak but adequate for mixing at Nisqually Reach;

b. Mixing for low and medium fallout flow appeared adequate at Tykle Cove and there appeared to be a net transport out of the inlet. The surface float result was erratic, indicating possible problems with transport at the surface; and

c. The Budd Inlet entrance channel (near existing outfall) showed very weak flows and the surface floats showed an undefined pattern during ebb and were beached. The floats at depth in the channel did follow the channel and were weak, but did indicate a net transport out.

This study, like the previous effort by Devitt (1974), had a major flaw in that drogue/dye movement was tracked for only a short period, almost entirely during outgoing tide.

Additional insight concerning circulation patterns in Budd Inlet is provided by Westley, et al. (1973). Based on an assessment of water chemistry (salinity, temperature, ammonia, BOD, etc.) sampled at depth over a large grid of stations, a general description of water movement in the inlet was obtained. Moos (1976) summarized the findings as follows:

> "One of the findings of that study was that the Olympia domestic wastewater contains varying amounts of ammonia, phosphates, suspended solids (filterable) and turbidity. At times the effluent plume was traced for about 0.4 mile north of the sewer outfall. Other times only a small effect was observed at the discharge site.

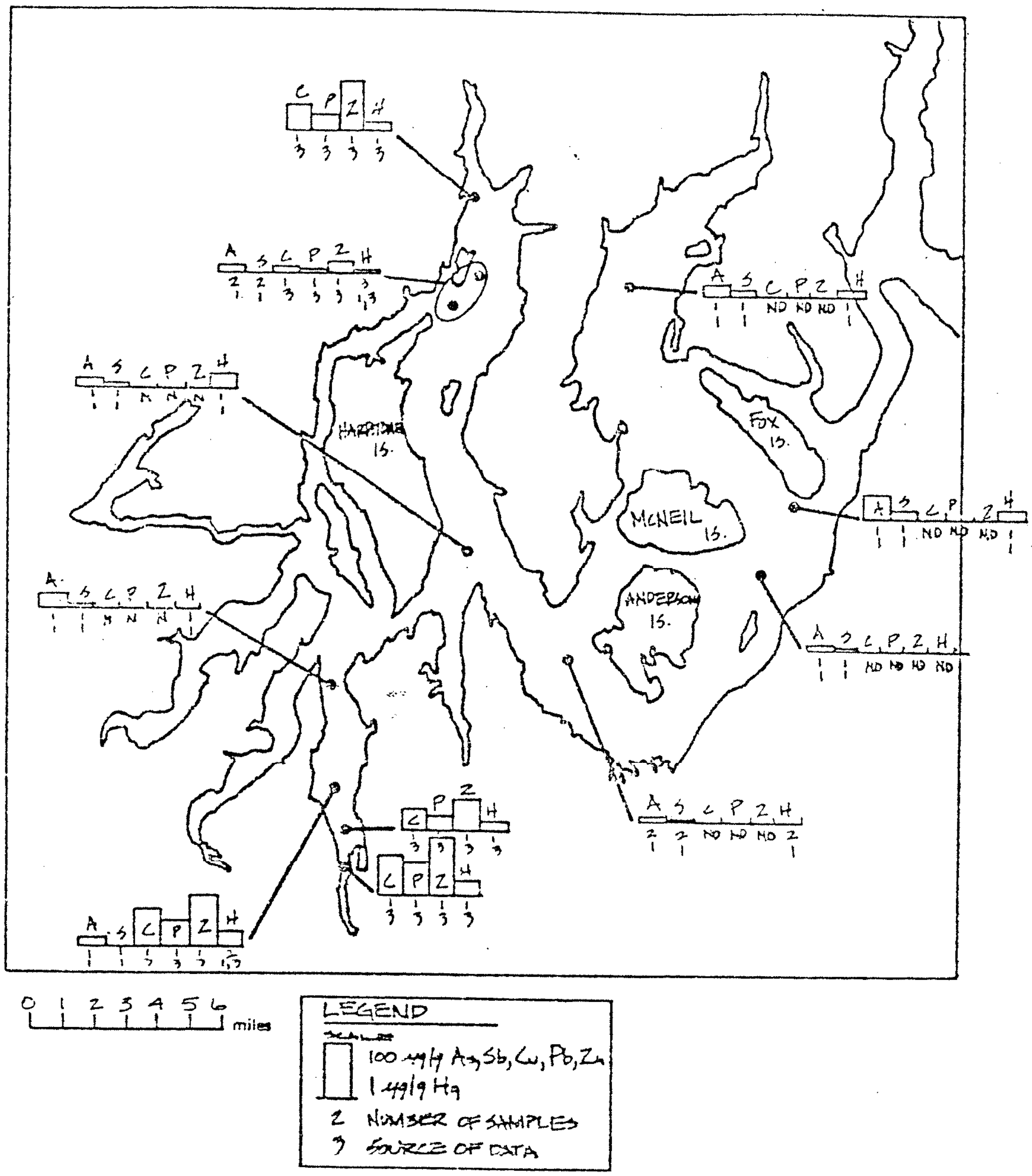


Figure 2 Concentrations of Selected Trace Metals Observed in the Sediments of Budd Inlet and the Southern Sound.

Data from 1) Crecelius et al., 1975; 3) Malins et al., 1980.

Source: Dexter, et al (1981)

dilution and dispersion characteristics for specific locations within the inlet. The studies suggest that the lower inlet is not a favorable site because of sluggish water movement and transit distance to the open waters of lower Puget Sound. Conditions appear to generally improve in the outer inlet.

3. Toxic Pollutants

Metals and organics were considered. Each category is discussed separately below. It is important to note that such contaminants may be partitioned into three areas of the aquatic environment (excluding aquatic biota): sediments; water; and suspended particulate matter.

Metals

Bottom sediments from only a few stations in Budd Inlet have been sampled for trace metals. The available data as presented by Dexter, et al. (1981) are shown in Figure 2. Based on these data, it was concluded that the sediment metals are at or near background levels for Puget Sound. The higher concentrations of Cu, Pb, Zn, and Hg observed at the southerly end of the inlet suggested a possible source. However, this was thought to be response to the deposition of fine-grained, organic-rich particulates and not likely due to anthropogenic sources.

Riley, et al. (1980) measured concentrations of trace metals in a sample of suspended matter collected from Budd Inlet (about the middle) with the following results:

Concentration in ppm dry weight

Arsenic	Chromium	Copper	Nickel	Lead	Zinc
<22	24	47	12	26	180

These levels are considered similar to those reported for suspended matter from "clean" stations such as Sequim Bay and the Washington Coast (Ibid.).

The data base on dissolved metals appears to be very limited.

Organic Contaminants

Dexter, et al. (1981) evaluated the distribution and concentrations of three groups of organic chemical contaminants

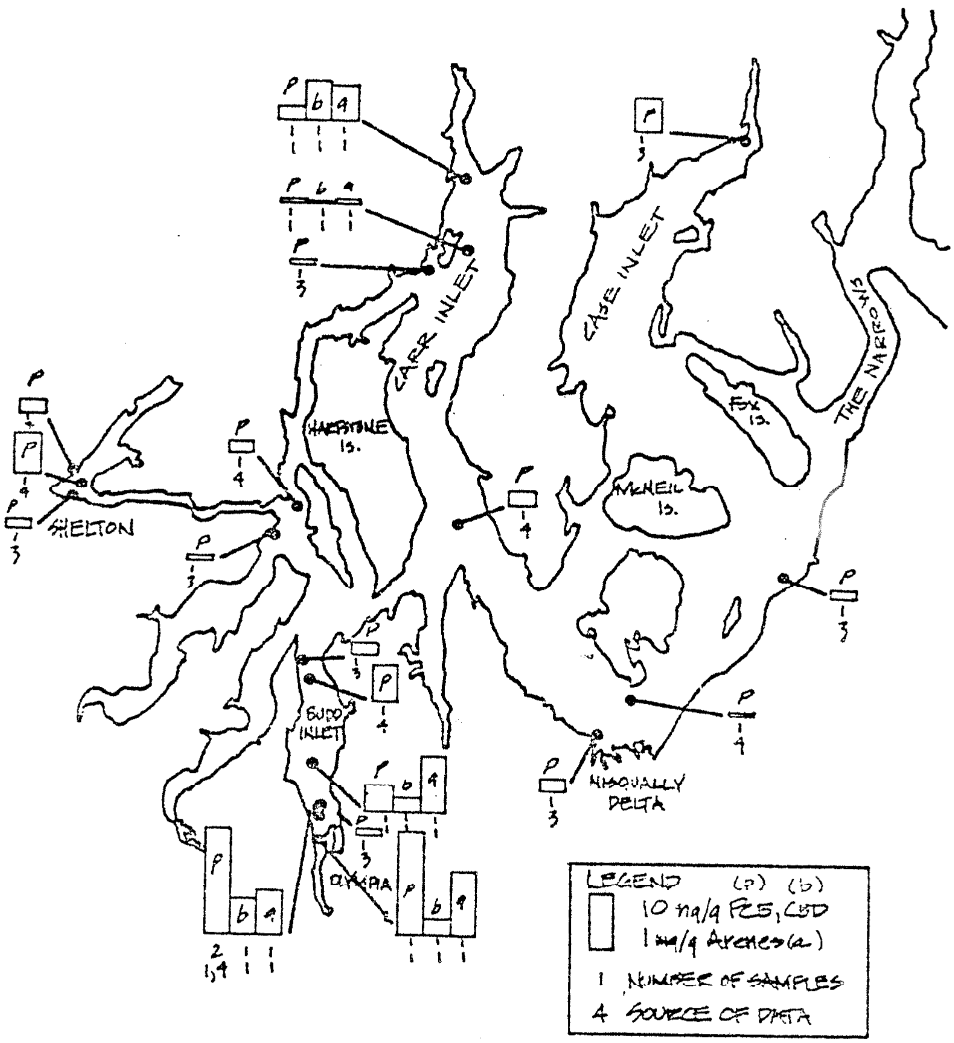


Figure 3 Concentrations of PCBs, CBDs and Arenes Observed in the Sediments of Budd Inlet and Other Areas of the Southern Sound.

Data from 1) Malins et al., 1980; 3) Mowrer et al., 1977; 4) Pavlou et al., 1977.

Source: Dexter, et. al.; 1981

considered principally of anthropogenic origin because natural occurrence is very limited or they are totally man-made. These included:

a. Polychlorinated biphenyls (PCBs) - are made by the chlorination of biphenyl. There are some 209 possible compounds and isomers of this group which is one of the most widely distributed pollutants on earth. This group is persistent, bioaccumulates, and some types are considered carcinogenic.

b. Chlorinated Industrial Compounds (CBDs) - originate mainly from disposal of industrial wastes. Some of the better known compounds include dichloromethane, trichloroethylene, tetrachloroethylene, chlorinated butadienes, and others which are included on the EPA list of priority pollutants. Only a few of these pollutants have been identified.

c. Arenes - are multi-ringed aromatic hydrocarbons associated mainly with petroleum products and combustion of organic fuels. Some are considered mutagenic and carcinogenic.

Concentrations of PCBs, CBDs, and Arenes observed in the sediments of Budd Inlet and other areas of southern Puget Sound are shown in Figure 3. Dexter, et al. (1981) summarizes these data as follows:

> "The concentrations of PCBs and Arenes observed in the mid-inlet sediments of Budd Inlet appeared elevated in comparison to the background sediments from undeveloped areas of the southern Sound.
>
> PCBs showed the greatest enrichment, roughly by a factor of 10, and also an increasing trend of concentrations toward the head of the inlet. However, in comparison with PCB levels in most areas of the Main Basin and its tributary embayments (e.g., Hood Canal and Whidbey Basin), the concentrations in Budd Inlet, and the southern Sound, in general, were low.
>
> The Arenes were elevated by a factor of two compared to the levels in Case Inlet. This difference may not be significant, but rather may result from differences in the sediment characteristics. CBDs were observed at background levels in Budd Inlet."

TABLE 3

MEAN CONCENTRATIONS OF PCBs, CBDs, HEXACHLOROBENZENE (HCB), AND 3- TO 5-RING ARENES IN ENGLISH SOLE LIVERS FROM REGIONS OF PUGET SOUND.[a]

Sampling Location	Concentrations, ng/g dry weight			
	PCB	CBD	HCB	3-5 Ring Arenes
Elliott Bay				
Duwamish River (1)[b]	35290	3	20	110
South Bay (3)	19170±11230[c]	4±5	13±6	NQ
Seattle Waterfront (1)	9210	12	20	NQ
Magnolia Bluff (2)	3470	NQ[d]	10	NQ
Eastern Main Basin (2)	2335	3	7	NQ
Port Madison (1)	2970	4	10	NQ
Sinclair Inlet (1)	8550	3	10	NQ
Commencement Bay				
Hylebos Waterway (5)	15140±3830	3200±3373	1850±1200	430±490
Outside of Hylebos (3)	9827±5608	115±136	110±142	880±1510
Southwest Bay (1)	4960	10	60	NQ
Brown's Point (1)	6350	10	120	NQ
Budd Inlet (1)	1920	12	10	NQ
Case Inlet (1)	1600	5	10	50

a Data from Malins et al., 1980.

b Number in parentheses indicate number of samples taken.

c Mean and one standard deviation.

d NQ indicates levels were not quantifiable.

Source: Dexter, et al (1981)

TABLE 2

MEAN CONCENTRATIONS OF PCBs, CBDs, HEXACHLOROBENZENE (HCB) AND 3-TO 5-RING ARENES IN ZOOPLANKTON AND BENTHIC SHRIMP FROM REGIONS OF PUGET SOUND.

Sampling Location	Concentrations, ng/g dry weight			
	PCB	CBD	HCB	3-5 Ring Arenes
Strait of Juan de Fuca (1)[a,b]	70	-[e]	-	-
Whidbey Basin (12)[b]	955±701[d]	-	-	-
Hood Canal (4)[b]	118±87	-	-	-
Main Basin (8)[b]	825±769	-	-	-
Port Madison (1)[c]	304	10	1	120
Sinclair Inlet (1)[c]	680	NQ[f]	0.4	950
Elliott Bay (9)[b,c]	961±380	NQ	1	160
Duwamish River (1)[c]	2050	NQ	2	480
Hylebos Waterway (1)[c]	3054	150	80	1210
Brown's Point (1)[c]	335	2	20	290
Budd Inlet (1)[c]	226	NQ	1	340
Case Inlet (1)[c]	134	5	NQ	1380

a Numbers in parantheses indicate number of samples taken.

b Data from Clayton, 1975 (zooplankton).

c Data from Malins et al., 1980 (benthic shrimp).

d Mean concentrations and standard deviation.

e A dash indicates no data were collected.

f NQ indicates that levels were not quantifiable.

Source: Dexter, et al. (1981)

TABLE 5

ANNUAL INCIDENCE OF SELECTED ABNORMALITIES OBSERVED IN REPRESENTATIVE BENTHIC CRUSTACEA FROM AREAS OF PUGET SOUND

Sampling Area	Shrimp, Pandalus danae				Total No. Examined	Crab, Cancer gracilis				Total No. Examined
	HN[a]	HV	GN	GMI		HTM	HV	GN	BL	
Sinclair Inlet	1(12)[b]	2(33)		0	6	0	2(40)	0	0	5
West Point	0	1(20)		0	5	0	0	0	0	0
Seattle Waterfront	5(56)	3(33)		0	9	2(28)	3(41)	1(15)	1(14)	7
Duwamish River	0	28(68)		3(7)	41	0	2(40)	2(40)	4(80)	5
Waterways of Commencement Bay	3(21)	2(14)		0	14	3(27)	4(36)	1(10)	2(18)	11
Hylebos	8(18)	23(51)		4(9)	45	1(10)	6(60)	0	2(20)	10
Budd Inlet	0	1(25)		0	4	0	4(57)	0	0	7
Case Inlet	0	0		0	8	0	3(43)	0	0	7

a HN = hepatopancreatic necrosis; HV = vesicular hepatopancreas; GN = melanized nodules in the gills; GMI = mycotic gill infection; HTM = hepatopancreatic tubular metaplasia; BL = bladder lesions.

b Data are presented as the numbers of diseased organisms observed, with the percentage of diseased fish of the total examined, included in parentheses for non-zero values.

Source: Malins, et al (1980)

TABLE 4

ANNUAL INCIDENCES OF SELECTED TOXIPATHIC LIVER ABNORMALITIES OBSERVED IN ENGLISH SOLE FROM AREAS OF PUGET SOUND

Sampling Area	Incidence of Selected Abnormalities				Total No. of Fish Sampled
	MH[a]	FHH[a]	HAF[a]	CF[a]	
Port Madison	1(3)[b]	1(3)	0	0	29
Sinclair Inlet	0	0	0	0	91
West Point	0	0	0	0	31
Outer Elliott Bay	0	0	0	0	77
Seattle Waterfront	7(9)	1(1)	0	0	82
Duwamish River	25(12)	0	4(2)	1(0.5)	210
Brown's Point	2(6)	0	0	0	32
SW Commencement Bay	0	0	0	0	80
Waterways of Commencement Bay	12(9)	10(7)	1(1)	4(3)	138
Hylebos Waterway	6(5)	6(5)	2(2)	2(2)	129
Budd Inlet	0	0	0	0	70
Case Inlet	0	0	0	0	34

a MH = megalocytic hepatosis; FHH = focal hepatocellular hyperplasia; HAF = hepatocellular adenomatous foci; CF = cholangioproliferative foci.

b Data are expressed as numbers of diseased fish for each type of malady. For non-zero incidences, the percentage of the diseased fish of the total number examined is included in parentheses.

Source: Malins, et al (1980)

Date	Location	Estimated Number of Fish Killed	Cause
3/18/73	Butler Cove	Unknown; 5 flounder washed ashore	Unknown
9/14/73	West Bay near Lake outlet	Unknown	Several possibilities cited -- Prior to kill an STP bypass occurred, Capitol Lake outflow cut off to fill lake, appeared to be algal bloom in progress.
6/2/81	Fiddlehead Marina and other parts of West Bay	40,000 chinook smolts	Several possibilities cited -- STP bypass, sludge beds associated with STP outfall.
9/9/81	West Bay near Capitol Lake outlet	315,000 including non-game species and 100 salmonids	Hydrogen sulfide discharged from Capitol Lake and low dissolved oxygen conditions in lower Budd Inlet aggravated by STP discharge.

The number of fishkills reported in lower Budd Inlet relative to other areas of the state suggests a susceptibility to such problems. Even if all the causes identified in the historical record were eliminated, the potential for problems would still exist. Since the LOTT plant is the major discharge, a plant upset might cause a substantial kill in the lower inlet, if it occurred during the critical late summer months. The probability of such an occurrence will become greater if existing discharge is increased.

5. Nutrients/Algal Production/Dissolved Oxygen

An initial review of available data for Budd Inlet and southern Puget Sound indicates that the LOTT plant is a substantial source of nutrients, including phosphorus and inorganic nitrogen forms. Nutrient enrichment is most marked in inner Budd Inlet near the plant discharge, but indications of elevated nutrient concentrations are detectable at numerous south Sound locations.

Further, it appears that during periods of high algal productivity (May through October) nitrate and other inorganic nitrogen forms (ammonia, nitrite) can limit algal growth. The subsequent settling

Riley, et al. (1980) collected a single sample of water and suspended particulate matter from Budd Inlet (July 1979) and found only a few Arenes at low concentrations.

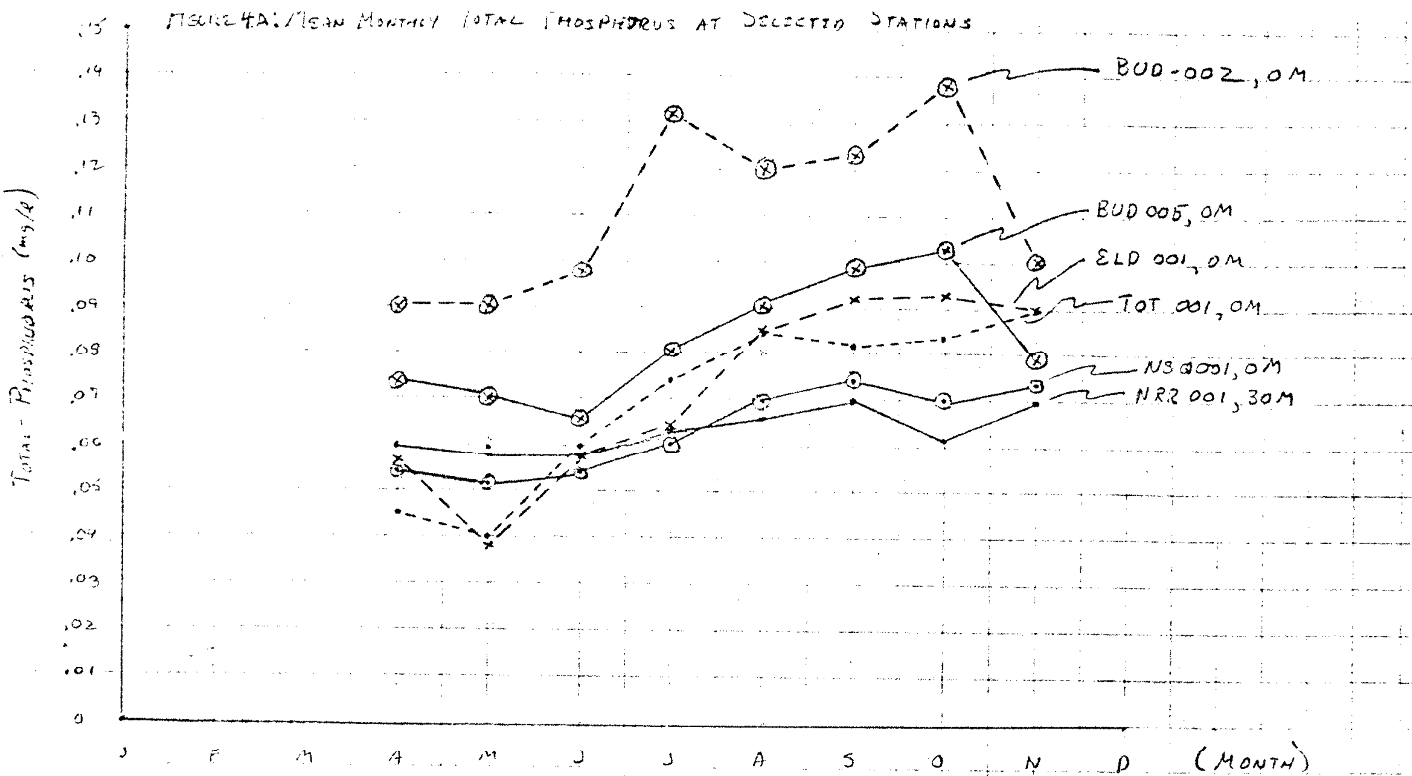
Concentrations of PCBs, CBDs, and Arenes in the water column would be expected to be very low due to their low solubility and tendency to accumulate in the particulate phases.

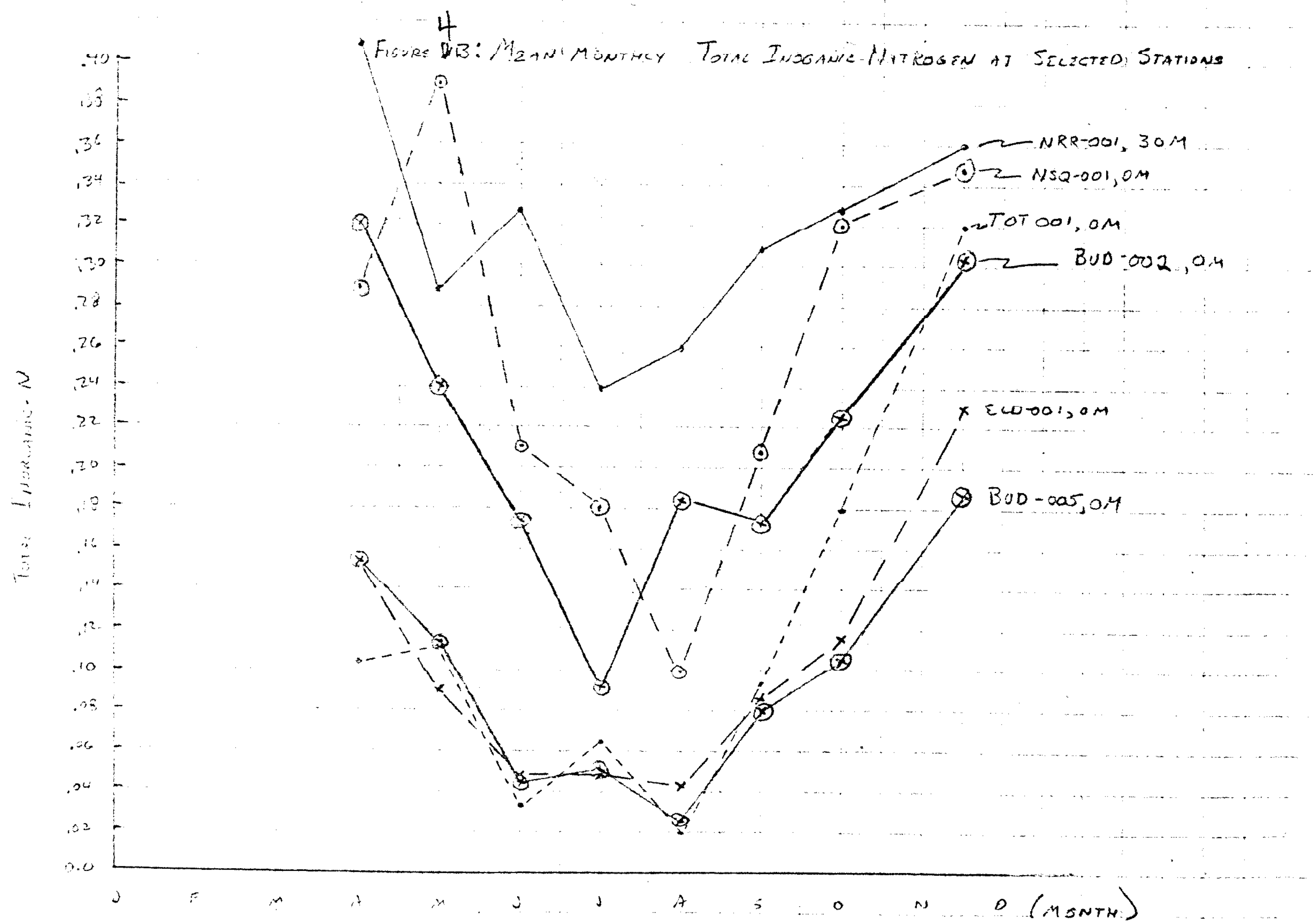
4. Biological Considerations

A limited amount of information has been collected on trace organic contaminants in aquatic organisms of Budd Inlet (Tables 2 and 3). It would be difficult to say much since the concentrations given for both benthic shrimp and English sole liver are based on a single sample. At best, Budd Inlet was in the general range of the other southern Puget Sound areas sampled. The CBDs in the inlet were higher than Elliott Bay. Dexter, et al. (1981) postulated that this may have been due to analytical or natural variance.

Malins, et al. (1981) sampled Budd Inlet English sole for selected liver abnormalities as part of an overall study of fish disease in Puget Sound. There were no abnormalities observed for the 70 fish sampled in Budd Inlet (Table 4). High incidences of disease occurred in the industrialized areas of Elliott Bay and Commencement Bay. Some abnormalities were observed in shrimp and crab collected from Budd Inlet (Table 5) (Ibid.). The sample size was quite small. Confirmation would be needed before conclusions could be made regarding these data.

Fishkills provide an indication of susceptibility to water pollution problems. The Department of Ecology is responsible for investigating such incidents on a statewide basis. Resource damage claims are developed in those cases where negligence or intent is involved and the responsible party is known. Fishkills for the most part are sporadic in nature, with less than 20 incidents reported each year. This does not reflect the number that actually may occur since many kills are either not reported or go unnoticed. Most fishkills are one-time events, although some water bodies have chronic problems. Lower Budd Inlet appears to fit the latter category based on the following list of incidents reported over the past 10 years:





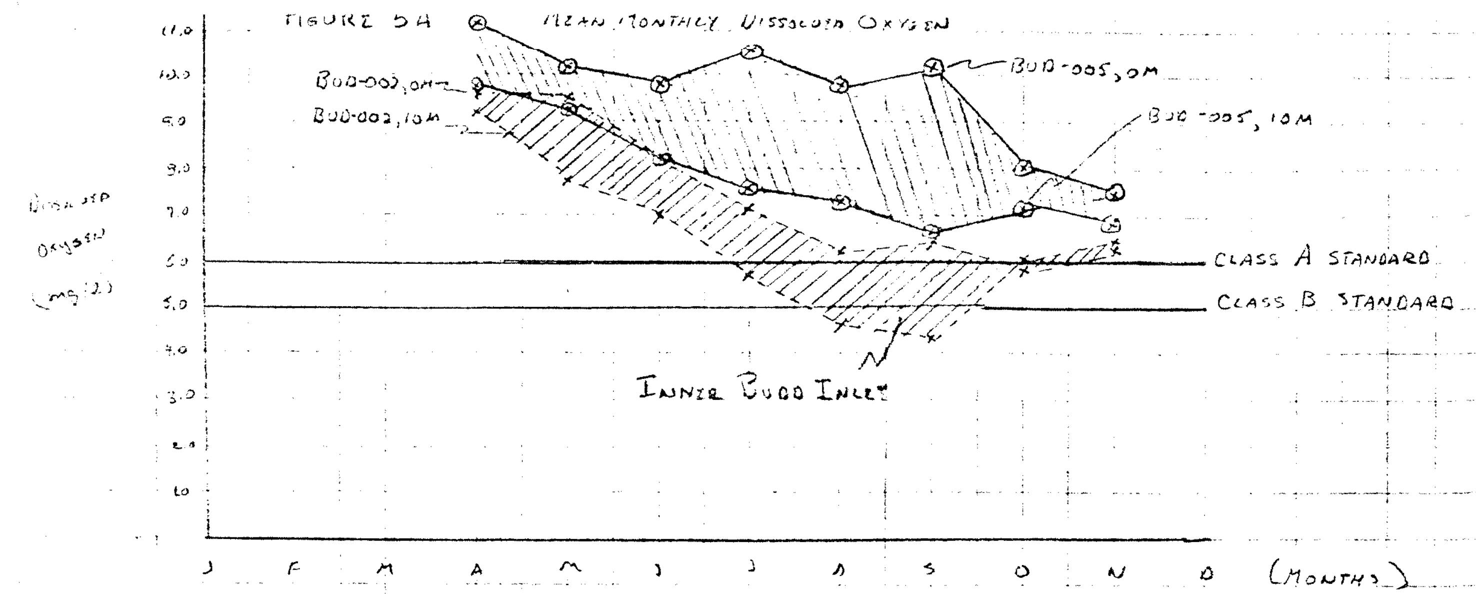
Figures 4A and 4B: SEASONAL NUTRIENT CONCENTRATIONS IN SOUTH PUGET SOUND and decay of algae can result in depressed dissolved oxygen concentrations. This implies that nutrients (particularly nitrogen forms) discharged from the LOTT plant may be significantly aggravating algal bloom problems in Budd Inlet, which in turn may aggravate the dissolved oxygen problems in the inlet.

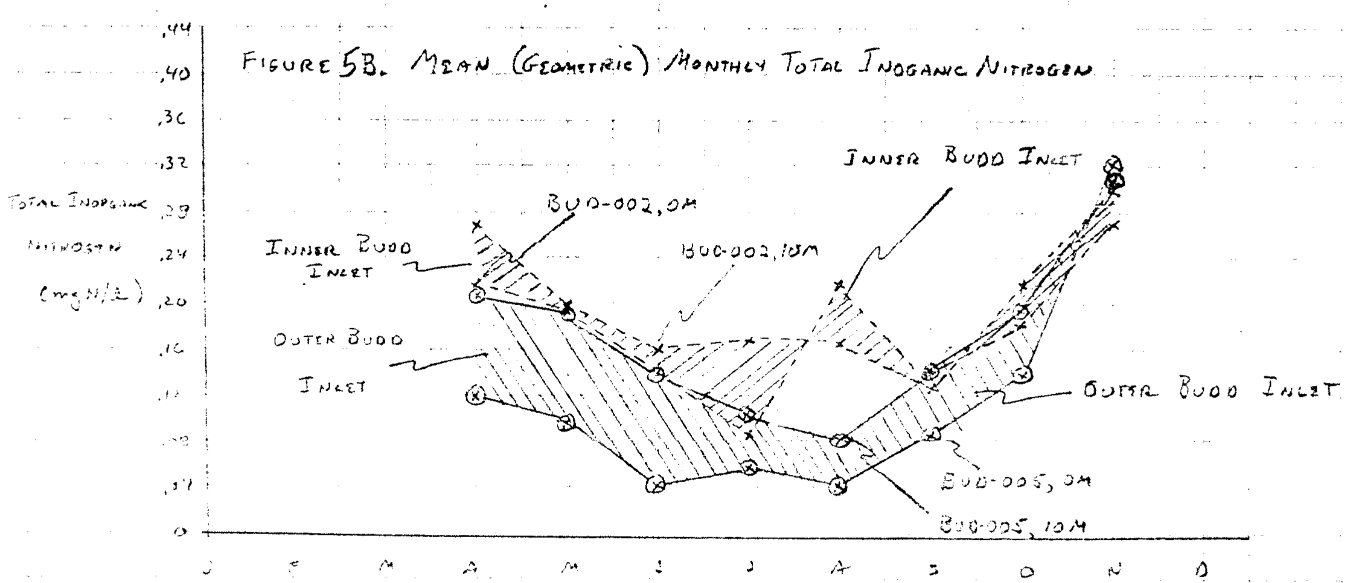
This section discusses some of the evidence which supports the hypotheses outlined above. It should be noted that the recent upgrade of the LOTT facility (primary to secondary treatment) was not designed to reduce nutrient loading to the inlet. It is, however, possible that a marginal decrease in effluent nutrient concentrations may have occurred due to the increased sludge production associated with secondary treatment. Receiving water data currently available for analysis represent conditions prior to the LOTT facility upgrade.

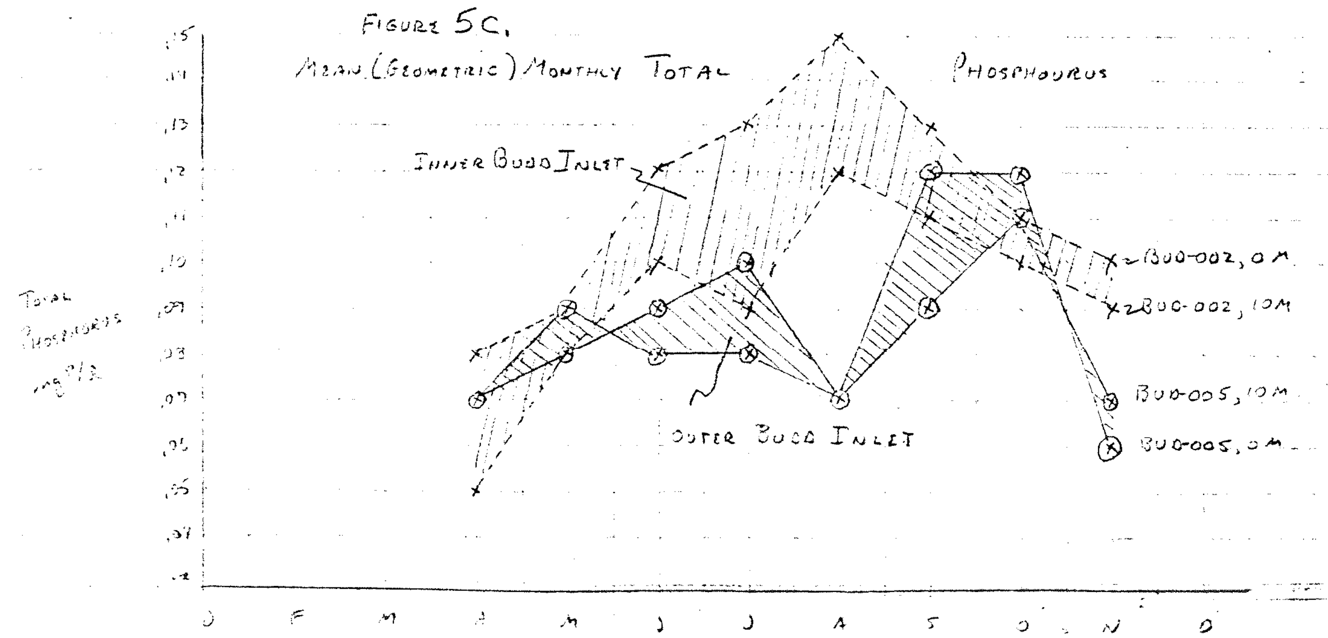
Many of the data presented here are obtained from WDOE's ambient network. Station locations are depicted in Figure 1. Station names and code numbers are listed below:

Station Number	Station Name
NRR-001	Tacoma Narrows near Point Defiance
NSQ-001	Nisqually Reach near Nisqually River
ELD-001	Eld Inlet near Flapjack Point
TOT-001	Totten Inlet near Windy Point
BUD-002	Budd Inlet S. Second Olympia Port Dock
BUD-005	Budd Inlet - Olympia Shoal at Horn

Figures 4A and 4B present seasonal fluctuations in nutrient (total phosphorus and inorganic nitrogen) concentrations in surface waters at various south Sound locations. From Figure 4A it is clear that, in general, as one moves from the Narrows toward the LOTT discharge in inner Budd Inlet, total phosphorus concentrations increase. Possible mechanisms for this increase will be discussed subsequently, but the substantially higher phosphate concentrations in inner Budd Inlet (BUD-002) are almost certainly due primarily to the LOTT discharge. The significance of total phosphorus concentrations is that they provide a measure of both inorganic and organic (algal and zooplankton) phosphorus. Because total phosphorus measures are not directly affected by algal uptake, they can provide a good measure of overall nutrient enrichment even in cases where phosphate is not growth-limiting. This, of course, only applies if the limiting nutrient (in this case, nitrogen) has the same sources as phosphorus and behaves in a similar manner.







Figures 5A and 5B. Comparison of Seasonal Nutrient and Dissolved Oxygen

Some misunderstandings appear to have developed regarding nutrient limitations to algal growth in Puget Sound in general and Budd Inlet in particular. For instance, Kruger (1979) states, "Primary productivity in Budd Inlet does not appear to be nutrient limited" (p. 13) and "Puget Sound waters are naturally abundant in nutrients throughout the year" (p. 33). Such statements seem, at least in part, to derive from studies like that of Winter, Banse, and Anderson (1975) which states, "Algal growth in the open waters of the central basin of the Sound is dominated by a number of intense blooms beginning in late April or May and recurring throughout the summer. Rarely, and only briefly, does nitrate become exhausted."

An important point here is that the latter quote refers specifically to the "open waters of the central basin" (emphasis added) and not to surface waters in stratified embayments and inlets. Review of nitrate data from stations throughout the Sound indicates that nitrate depletion (to or below the detection limit of .01 mg NO_3-N/L) is common in embayments which stratify and/or experience poor mixing (Yake, 1981). Dr. Karl Banse (1983), a co-author of the Winter, et al., publication, has indicated that algal productivity may often be nitrate-limited in the euphotic zone of embayments.

Figure 4B depicts seasonal total inorganic nitrogen (NO_3 + NO_2 + NH_3-N) concentrations in surface waters at southern Puget Sound locations. Some seasonal depletion is apparent at all sites, but mean monthly concentrations approach zero during June, July, and August at three stations located in Budd, Eld, and Totten inlets. Note that each point on the graph represents the average of five to seven data points (one per month per year for five to seven years). Thus, at any given point in time, concentrations well above or below the mean may occur. It is, however, apparent that inorganic nitrogen depletion, and thus potential algal production, is often nitrogen-limited.

The linkages between nutrients discharged from the LOTT plant and primary productivity, water clarity, and dissolved oxygen concentrations in Budd Inlet and southern Puget Sound are less well defined. Figures 5A and 5B compare dissolved oxygen and nutrient concentrations at two Budd Inlet stations. As may be noted in Figure 5A, Budd Inlet is relatively strongly stratified with higher oxygen concentrations in the surface waters. Dissolved oxygen concentrations are lower in inner Budd Inlet while nutrient concentrations are higher. Localized dissolved oxygen depression in inner Budd Inlet has been attributed to biochemical oxygen demand in the poorly treated, pre-upgrade LOTT effluent (Stanley and Cloud, 1975; Yake, 1981). However, it appears these incidences affected only isolated portions of inner Budd Inlet and that, in general, algal decay is probably the major mechanism responsible for depressed

To help assess the impact of this nutrient load on water quality in Budd Inlet, Figure 6A-6C compare dissolved oxygen and nutrient concentrations at a station in Budd Inlet with those at a station in nearby Totten Inlet. Both locations record nearly identical inorganic nitrogen depletion curves in surface waters but Budd Inlet has much higher inorganic nitrogen concentrations at depth. The Budd Inlet station displays higher oxygen concentrations at the surface and lower oxygen concentrations at depth which may well be, at least in part, due to increased algal productivity and subsequent settling and decay. This condition appears to be aggravated by nutrient enrichment. It is possible that some of the differences in surface and depth concentration patterns at the two stations may be due to the constriction at the mouth of Totten Inlet which probably causes more intense mixing and destratification than occurs in Budd Inlet. None the less, there appears to be a substantial probability that effluent loading of nitrogen forms from the LOTT facility is aggravating algal blooms and subsequent dissolved oxygen problems in Budd Inlet.

The relative importance of LOTT as a nutrient source in southern Puget Sound is complicated to some extent by another consideration. Examination of Figure 4A reveals an increase in total phosphorus as one moves from the Narrows toward inner Budd Inlet. In addition, there appears to be a general increase in phosphorus concentrations from July through October. This pattern is most marked at the southernmost locations (Budd, Eld, and Totten inlets). It is possible that these patterns may be, in part, due to a phenomenon known as the "estuarine mechanism". As Parsons and Takahashi (1973) note "...a nutrient 'trap' may develop where the organisms grown at the surface, sediment to a layer where they are carried back into the inlet by the countercurrent to the surface flow." This can result in continued nutrient accumulation throughout the growing season.

Because of the lack of understanding regarding circulation, nutrient cycling, and algal bloom dynamics in southern Puget Sound, it is not currently possible to fully and precisely describe the impact of LOTT nutrient loading on water quality in the south Sound in general and Budd Inlet in particular. None the less, there is adequate *prima facia* evidence to suggest strongly that nutrient loading from the plant is aggravating algal blooms in (at least) Budd Inlet, resulting in turn in depressed dissolved oxygen concentrations, particularly at depth and near the head of the inlet. As Table 7 indicates, water clarity also appears to be impaired by excessive algal productivity.

oxygen concentrations (Kruger, 1979) in inner Budd Inlet and at depth (10 meters) at the Olympia Shoal station (BUD-005).

There are numerous potential sources of nutrients to Budd Inlet; however, the majority of nutrient loading is probably limited to three major sources: (1) incoming marine waters; (2) the Deschutes River; and (3) the LOTT plant. Accurate estimates of nutrient loading from incoming marine waters are not presently available; however, one can assume that without additional loads from the Deschutes and LOTT plant, Budd Inlet nutrient concentrations would be equivalent to those in Eld and Totten inlets. As noted in Figure 4A, total phosphorus concentrations are measurably higher. This elevation in concentrations is most likely due to the fresh-water sources noted above. To provide a perspective on the relative importance of these two sources, Table 6 summarizes LOTT (pre-upgrade) effluent loading and Deschutes river loading for the months of April through November. LOTT effluent loading estimates are based on four composite samples obtained in February and March of 1982. More recent (May 1983) analyses by the LOTT facility indicate similar loads from the new secondary plant. Deschutes River loading is derived from WDOE ambient monitoring data from station 13A060 (Deschutes River at E Street Bridge).

Table 6. Comparison of nutrient loading for LOTT facility and Deschutes River.

	Total Inorganic Nitrogen (lbs/day)				Total Phosphorus (lbs/day)			
Month	LOTT	Deschutes River	Total	Percent from LOTT	LOTT	Deschutes River	Total	Percent from LOTT
April	1140	926	2066	55%	485	96	581	93%
May	1140	505	1645	69%	495	28	513	95%
June	1140	529	1669	68%	485	28	513	95%
July	1140	302	1442	79%	485	16	501	97%
August	1140	194	1334	95%	485	13	498	97%
September	1140	252	1392	82%	485	17	502	97%
October	1140	265	1405	81%	485	13	498	97%
November	1140	836	1979	58%	485	136	621	78%

As noted in Table 6, nutrient loading from the LOTT facility substantially exceeds Deschutes River loading, particularly during the months of June to August when nitrogen can most frequently limit algal growth.

Table 7. Average secchi disc readings - southern Puget Sound.

Station Number	Location	Avg. Secchi Disc Reading Meters	Feet
NRR-001	Tacoma Narrows	7.49	24.6
NSW-001	Nisqually Reach	6.01	19.7
TOT-001	Totten Inlet	3.67	12.0
ELD-001	Eld Inlet	3.60	11.8
BUD-005	Outer Budd Inlet	3.51	11.5
BUD-002	Inner Budd Inlet	2.05	6.7

DISCUSSION

Budd Inlet waters appear to be very susceptible to pollution, at times experiencing severe stress under existing conditions. The problems are most pronounced in the lower reach where water circulation is poorest. Some of the existing problems at least in part are associated with mans' activities including the LOTT wastewater treatment plant.

A list of water quality issues likely to arise as LOTT Phase II proceeds are listed in order of priority below:

1. A major issue. Little is known about the ability of the inlet to assimilate wastewaters through dilution and dispersion processes. Data on specific discharge locations are extremely limited. This is particularly true of the lower inlet where circulation appears to be the poorest and water quality problems most pronounced.

2. A major issue. The LOTT plant has been identified as a substantial source of nutrients. Available data suggest this source may play a significant role in the algae bloom problem which has plagued the inlet in past years. The nutrient loading also may contribute indirectly to the dissolved oxygen problems which have occurred.

3. A major issue. The number of fishkills reported over the last 10 years in the lower inlet suggests susceptibility to such problems. Even if all of the causes historically identified were eliminated, a substantial kill could result if a plant upset occurred, with the late summer months being the most critical period.

4. A possible major issue. Lower Budd Inlet is rated highest (worst water quality) of all marine areas evaluated as part of the

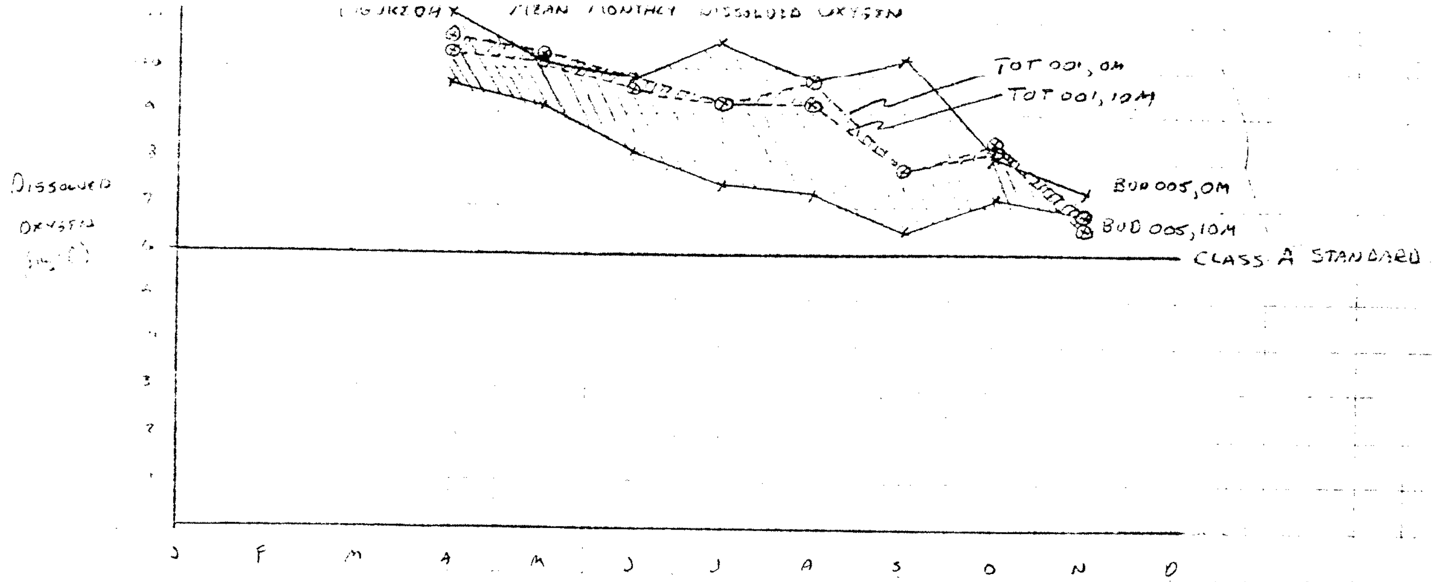


FIGURE 6A: MEAN MONTHLY DISSOLVED OXYGEN

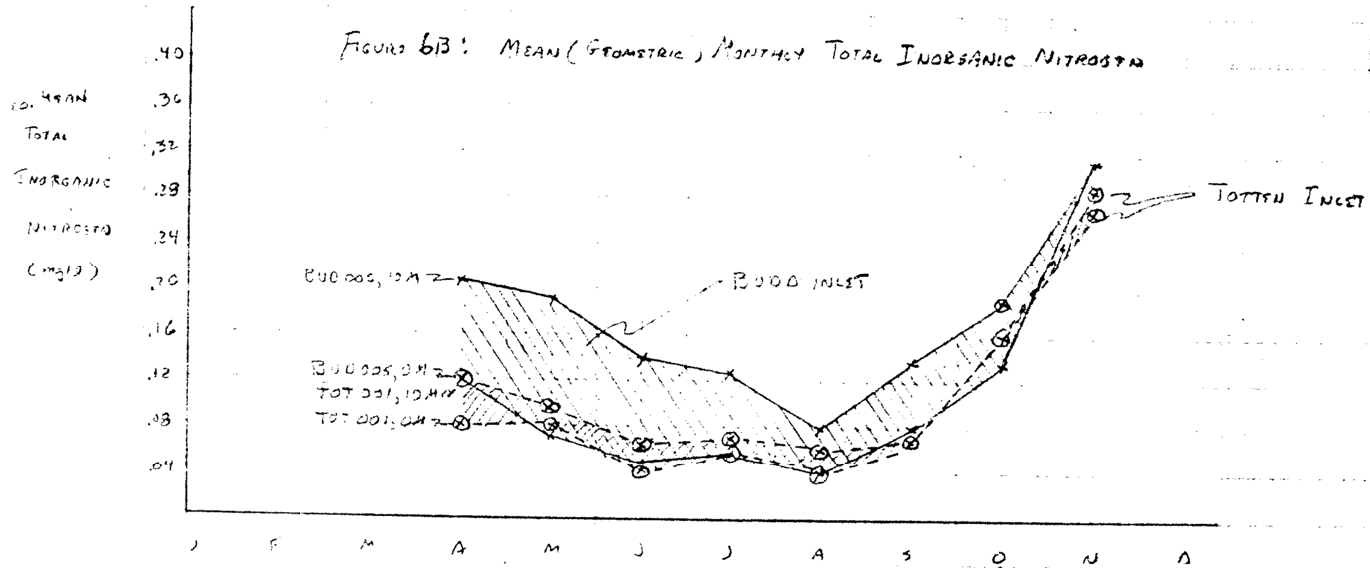


FIGURE 6B: MEAN (GEOMETRIC) MONTHLY TOTAL INORGANIC NITROGEN

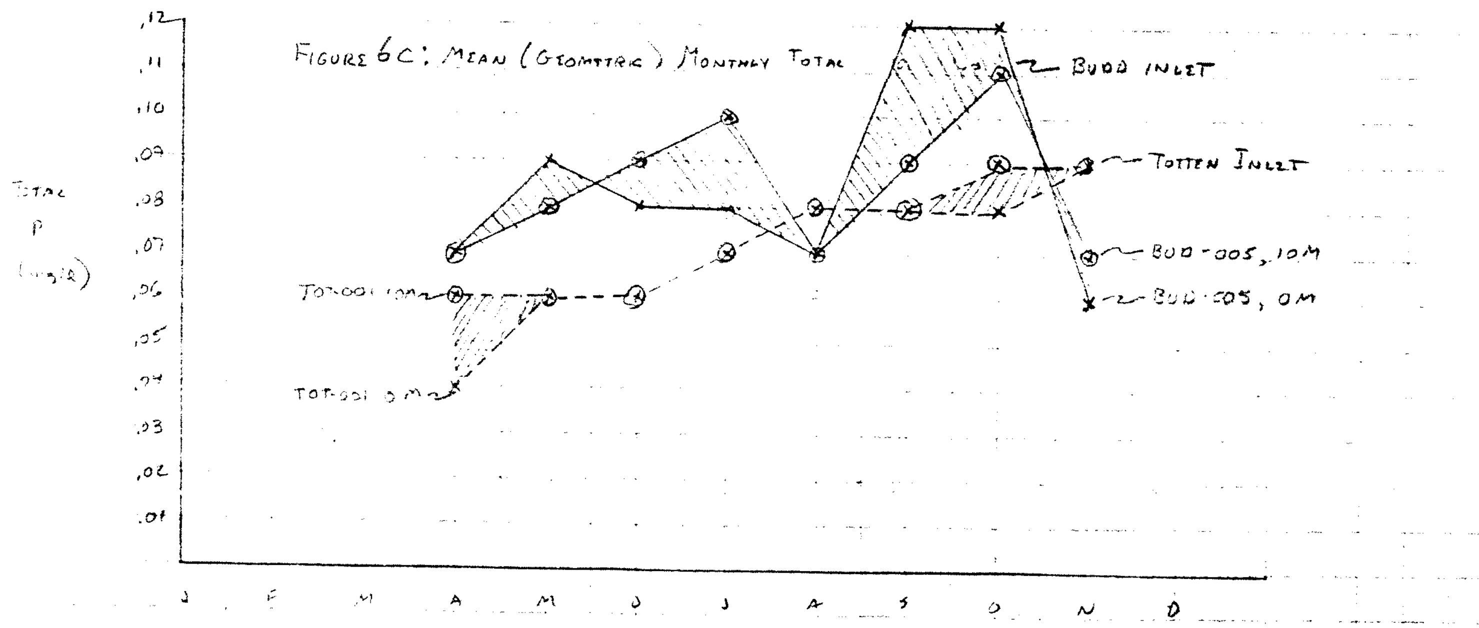
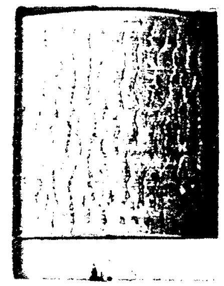
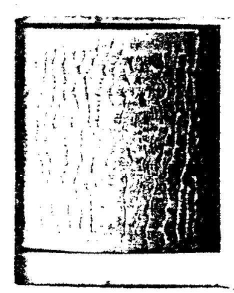


FIGURE 6C: MEAN (GEOMETRIC) MONTHLY TOTAL

Figures 6A – 6C: A COMPARISON OF SEASONAL NUTRIENT AND DISSOLVED OXYGEN CONCENTRATIONS IN BUDD AND TOTTEN INLETS





Department's WQI rating system. The rating under current conditions may be somewhat better than indicated, assuming the new LOTT plant has helped reduce bacterial levels in the inlet.

5. A potential issue. Toxic pollutants including heavy metals and organic chemical contaminants do not appear to be a problem in the inlet at present. However, very limited information is currently available on this area of environmental study which has received increased interest in recent years.

6. A potential issue. The limited amount of data available on disease and tissue abnormalities in aquatic organisms does not suggest problems. Again, additional information is needed in this area.

In conclusion, perhaps the most serious problem currently facing water quality specialists is that too little is presently known about the ability of Budd Inlet to assimilate waste loads. Informed management decisions concerning the inlet's future are not possible. What little is known suggests the inlet is environmentally quite sensitive, particularly near the lower end, and the capacity to handle some wastewater constituents such as nutrients may be exceeded even under existing conditions. For these reasons, a detailed study of possible water quality impacts is necessary before Budd Inlet is seriously considered for additional wastewater disposal. A hydraulic water quality model should be developed which can not only evaluate dilution and dispersion characteristics of potential discharge sites, but also predict the fate of those pollutants, conservative as well as non-conservative, of principal concern. The nutrient/algae/dissolved oxygen question is certainly one area. Such an effort would require considerably more knowledge of the system than currently exists. Also, there is the problem of lower Puget Sound and its overall capacity to assimilate wastes. This area includes the "compartment" south of Pickering and Dana passages (Figure 1).

Specific questions concerning the Water Quality Index, dilution and dispersion, toxic pollutants, and aquatic biota should be referred to John Bernhardt. The complex issue of nutrients/algae/dissolved oxygen was addressed by Bill Yake.

JB:BY:cp

LITERATURE CITED

Banse, K., 1983. Personal communication.

Collias, E.E., 1970. "Index to Physical and Chemical Oceanographic Data of Puget Sound and its Approaches, 1932-1966." Univ. of Wash., Dept. of Oceanography Special Rept. No. 43.

Devitt, R.C., 1974. "Olympia STP, Budd Inlet Dye Survey and Aerial Photographs", State of Wash., Dept. of Ecology, Departmental Memorandum. 13 pp.

Dexter, R.N., D.E. Anderson, E.A. Quinlaw, L.S. Goldstein, R.M. Strickland, S.P. Pavlou, J.R. Clayton, Jr., R.M. Kocan, and M. Landolt, 1981. "A Summary of Knowledge of Puget Sound Related to Chemical Contaminants", NOAA Technical Memorandum OMPA-13. 435 pp.

Duxbury, A.C. and N.A. Friebertshauer, and E.P. Richey, 1972. "Budd Inlet Circulation and Flushing Study," in Water Pollution Control and Abatement Plan for Deschutes River Basin. WRIA 13, Arvid Grant and Assoc., Inc., Thurston Regional Planning Council.

KCM, 1975. "Alternate Sites for Wastewater Treatment and Disposal," Kramer, Chin and Mayo, Inc., Seattle, WA. 51 pp.

Kruger, D.M., 1979. "Effects of Point Source Discharges and other Inputs on Water Quality in Budd Inlet, Washington," State of Wash., Dept. of Ecology, DOE 79-11, 77 pp.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins, 1980. "Chemical Contaminants and Biological Abnormalities in Central and Southern Puget Sound," NOAA Technical Memorandum OMPA-2. 186 pp. and appendices.

McLellan, P.M., 1956. "An Area and Volume Study of Puget Sound, Washington," Tech. Rept. No. 21, Univ. of Wash., Dept. of Oceanography. 40 pp.

Monn, B., 1982. "1982 Water Quality Index (WQI)" Departmental memorandum from Bob Monn, State of Wash., Dept. of Ecology, June 8, 1982. 19 pp.

Moos, D.W., 1976. Letter from Donald W. Moos to Paul B. Liao outlining comments on the LOTT Complex Facility Planning Study for Olympia, Lacey, Tumwater, and Northern Thurston County., State of Wash., Dept. of Fisheries, Februray 17, 1976, 3 pp.

Oclay, N., 1959. "Oceanographic Conditions near the Head of Southern Puget Sound: August 1957 through September 1958." Univ. of Wash., M.S. Report, 53 pp.

Riley, R.C., E.A. Crecelius, D.C. Mann, K.H. Abel, B.L. Thomas, and R.M. Beau, 1980. "Quantitation of Pollutants in Suspended Matter and Water from Puget Sound." NOAA Technical Memorandum ERL MESA-49. 59 pp. plus appendices.

Singleton, L. and J. Joy, 1981. "Water Quality Invex (WQI) Analysis of State Waterway Segments for the 1981 SEA," State of Wash., Dept. of Ecology, May 22, 1981. 44 pp.

Stanley, R. and G. Cloud, 1975. "Budd Inlet Summary of August 27, 1975." Memorandum to Dick Cunningham, August 28, 1975.

Westly, R.E., E. Finn, M.I. Carr, M.A. Tarr, A.J. Scholz, L. Goodwin, R.W. Sternberg, and E.E. Collias, 1973. "Evaluation of Effects of Channel Dredging and Disposal on the Marine Environment in Southern Puget Sound, Washington," 308 pp.

Winter, D.F., K. Banse, and G.C. Anderson, 1975. "The Dynamics of Phytoplankton Blooms in Puget Sound, a Fjord in the Northwestern United States." in Marine Biology 29, pp. 138-176

Yake, B., 1981. "Seasonal Nutrient Depletion at Ambient Marine Stations in Puget Sound; Implications for Discharge of Nutrients to Embayments like Budd Inlet." Memorandum to Dick Cunningham, December 22, 1981.

Yake, B., 1981. "Interpretation of June 3, 1981, Budd Inlet Data with Particular Respect to Oxygen Depletion." Memorandum to John Bernhardt, June 6, 1981.