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EFFECTS OF POINT-SOURCE DISCHARGES AND OTHER INPUTS ON WATER QUALITY IN BUDD INLET, WASHINGTON

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EFFECTS OF POINT-SOURCE DISCHARGES AND OTHER INPUTS ON WATER QUALITY IN BUDD INLET, WASHINGTON

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ABSTRACT

Water quality surveys were conducted on Budd Inlet during 1976-78 to obtain a baseline of data that can be used to evaluate benefits of various water pollution abatement projects planned for the Olympia area. Budd Inlet and all significant source waters were monitored including Olympia STP, combined storm sewer overflows, feeder streams, and incoming Puget Sound waters. Water quality analyses included nutrients, dissolved oxygen, fecal coliform bacteria, and other parameters. In addition, a mathematical model was developed to predict dissolved oxygen concentrations during summer low flow.

Incoming Puget Sound waters were found to naturally contain sufficient nutrients for a high algal bloom potential in Budd Inlet. The other sources did not significantly contribute to nutrient levels in the inlet. The model indicated that decaying natural algal blooms are the main cause of the dissolved oxygen (D.O.) sags that periodically occur in southern Budd Inlet during late summer.

Capitol Lake, Moxlie Creek, and Olympia STP each contributed approximately one-third of the fecal coliform loading to the inlet. Upgrading the Olympia STP disinfection equipment and eliminating all sanitary inputs to Moxlie Creek should reduce fecal coliform loading by 50 percent or greater.

Precipitation was below normal throughout the study. Loading rates for fecal coliform bacteria and other parameters presumably were less than under more adverse weather conditions.

Key words: Budd Inlet; water quality assessment; mathematical modelling.

ACKNOWLEDGEMENTS

I would like to give special thanks to John Yearsley, EPA Region X, for his assistance in the development and verification of the Budd Inlet dissolved oxygen model. Also, thanks to Jerome Thielen and Dale Tucker for their help in the collection and analysis of data during the study, John Bernhardt for his editorial comments, and to Carol Perez for her patience and dedication in typing this manuscript.

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SUMMARY

Budd Inlet is the southernmost waterway of Puget Sound and the main seaport of Olympia and adjacent communities. The inlet serves as a commercial lane for export and delivery of maritime goods. Many citizens also use the waters for fishing, boating, and a variety of other recreational activities. Aesthetically, the inlet is perhaps the most attractive aspect of the Olympia area.

The inlet experiences several water quality problems which reduce its value as a resource. Nuisance algal blooms periodically occur reducing water transparency. Dissolved oxygen drops to critical levels at times during summer resulting in fish kills. Fecal bacteria levels exceed the state's water quality standards during some periods. The public has become increasingly concerned about these problems in recent years, particularly in light of the rapid population growth and commercial development projected for lower Puget Sound.

In response to the need for more detailed information on Budd Inlet waters and factors which influence water quality, the Department of Ecology conducted a receiving water study from 1976 to 1978. The purpose of the study was to:

1. Better define the cause and effect of existing water quality problems; and

2. Obtain a baseline of data that can be used to evaluate benefits of various water pollution abatement projects planned for the Olympia area.

Budd Inlet waters and all significant discharges to the inlet were monitored including the Olympia sewage treatment plant, combined sewer overflows in and around Olympia, Deschutes River (Capitol Lake outlet), and other feeder streams. Water quality analyses included nutrients (phosphorus and nitrogen compounds), dissolved oxygen, fecal coliform bacteria, and other constituents. Phytoplankton (algae) samples were collected at selected sites. In addition, a mathematical model was developed to predict dissolved oxygen concentrations during summer low flow.

Results of the Budd Inlet study are succinctly described below.

Nutrient Inputs

Puget Sound waters flowing into the inlet by tidal action naturally contain sufficient phosphorus and nitrogen for a high algal bloom potential. The other monitored inputs do not significantly contribute to nutrient levels in the inlet.

Upgrading of the Olympia sewage treatment plant is now taking place. Under present conditions, there is no need to consider treatment greater than secondary or to extend the outfall into deeper waters. Water quality benefits associated with nutrient removal (tertiary treatment) would be minor compared to the cost.

Algal Blooms

The algal blooms which periodically occur in the inlet appear to be in direct response to the high nutrient levels that naturally exist. Availability of solar radiation appears to be the main limiting factor. Consequently, algal blooms may be expected to continue even after the new Olympia sewage treatment plant is in operation.

The decision not to include nutrient removal in the new treatment facility is supported by this finding.

Dissolved Oxygen

The mathematical model indicates that decaying algae (following algal blooms) is the main cause of the dissolved oxygen sags that periodically occur in southern Budd Inlet during late summer. Dissolved oxygen problems are expected to continue after the Olympia sewage treatment plant is upgraded.

The Deschutes River (Capitol Lake outlet) is the major contributor of dissolved oxygen to the inlet during late summer. Although it may not completely resolve the dissolved oxygen problem, a small continuous discharge during all phases of flushing Capitol Lake may add sufficient oxygen to prevent or minimize fish mortalities in the inlet.

Fecal Bacteria

Capitol Lake, Moxlie Creek, and the Olympia sewage treatment plant are the major sources of bacterial contamination in the inlet. Each contributes about one-third of the fecal bacteria loading. The Olympia sewage treatment plant upgrade, which also addresses the Moxlie Creek drainage basin, should reduce bacterial loading to the inlet by 50 percent or more. The Capitol Lake contribution, dominated by the Deschutes River and waterfowl on the lake, will not be appreciably affected.

A reduction in bacterial loading associated with the Olympia sewage treatment plant upgrade may improve water quality to the Class A designation for lower Budd Inlet (it is now Class B). These waters would then be classified as suitable for water-contact recreation.

INTRODUCTION

Budd Inlet is divided into two segments under the state's water quality management program. The outer inlet (Segment 25-02-00) currently meets the state's water quality classification for Class A marine waters (DOE, 1977). Inner Budd Inlet (Segment 06-13-03), south of Priest Point Park, is designated Class B marine waters. These waters do not meet the state standards for fecal coliform bacteria and dissolved oxygen.

The Olympia sewage treatment plant (STP), the major municipal point-source discharger to inner Budd Inlet, is scheduled for upgrade to secondary treatment (to be completed by 1982) under the USEPA/DOE municipal construction grants program. The new facility will substantially decrease biochemical oxygen demand (BOD) loading, improve bacterial disinfection through ozonation and, through sewer rehabilitation, eliminate raw sewage bypassing except during extreme storm events. Sewage wastes generated by the communities of Lacey, Olympia, Tumwater, and northern Thurston County (LOTT) will be served by the new facility.

An intensive water quality monitoring study was conducted in Budd Inlet during 1976 through 1978 to evaluate impacts of the various inflows on water quality. Three objectives were addressed:

(1) Identify, inventory, and determine the impacts of significant point source dischargers and other inputs to the estuary on fecal coliform bacteria, dissolved oxygen, and nutrient levels. These sources include the Olympia STP, combined storm sewer overflows, Capitol Lake discharge, feeder streams, and incoming Puget Sound waters.

(2) Identify the cause or causes of low dissolved oxygen conditions that historically prevail in southern Budd Inlet during late summer. A mathematical model for dissolved oxygen was developed as part of this objective. Morphologic and hydrographic characteristics of the inlet were also determined to provide the background data necessary in the calibration of the model.

(3) Evaluate, in terms of receiving water quality, two key management decisions made during the facility planning process for Olympia STP: (a) not to include tertiary treatment (nutrient removal) in the facility upgrade; and (b) not to relocate the sewage treatment plant outfall to deep waters beyond Priest Point Park.

It is anticipated that data collected during this study will provide a baseline for comparison when follow-up studies are conducted after the Olympia STP is upgraded or other events occur which may enhance water quality.

Supplementary to this text, complete field and laboratory data has been published and can be obtained from the Washington State Department of Ecology, Olympia, Washington 98504, publication number DOE 79-11a.

DESCRIPTION OF STUDY AREA

Budd Inlet is located at the southern terminus of Puget Sound. It is a narrow estuary measuring approximately 11.5 km in length, with maximum and average widths of 3.0 km and 1.7 km, respectively (Figure 1). The mean depth at MLLW (mean lower low water) is 9.3 meters. The maximum depth at MLLW is 33 meters at Boston Harbor. Table 1 lists the tidal characteristics for the inlet (Univ. of Wash., 1954).

Budd Inlet has no entrance sill and in general the intertidal beaches along the outer inlet are moderately steep. This changes to extensive intertidal flats at the southern end of the inlet near Capitol Lake dam and East Bay. Much of the subtidal area throughout the entire inlet is of a mud, clay, and silt mixture with some areas having a hard, compacted clay bottom. The major portion of the shoreline is residential, though the southern end of the inlet is urbanized and industrialized.

The principal freshwater inflow to Budd Inlet is from Capitol Lake, which has an average annual discharge of 170 MGD (263 cfs). Capitol Lake is an impoundment fed by the Deschutes River and Percival Creek. Water levels in the lake are regulated through the operation of a tide gate located at the northernmost end. During high tides the gates are closed, preventing salt water intrusion into the lake. During low tides the gates are opened, releasing freshwater into the inlet. Secondary freshwater inflows from Moxlie and Ellis creeks, at 8 MGD (12 cfs) and 7 MGD (11 cfs) respectively, are located on the east bay side of the inlet.

Table 1. Budd Inlet tidal characteristics at the Olympia bench mark.

Latitude	47° 03'	
Longitude	122° 54'	
Mean Range of Tide	3.5 meters	(11.5 feet)
Diurnal Range of Tide	4.4 meters	(14.4 feet)
Highest Tide (est.)	5.4 meters	(17.7 feet)
Mean Higher High Water (MHHW)	4.4 meters	(14.4 feet)
Mean High Water (MHW)	4.1 meters	(13.5 feet)
Half Tide Level	2.5 meters	(8.2 feet)
Mean Lower Water (MLW)	0.9 meters	(3.0 feet)
Mean Lower Low Water (MLLW)	0.0 meters	(0.0 feet)
Lowest Tide (est.)	-1.4 meters	(-4.6 feet)
Diurnal Tide Range Minus Mean Tide Range	1.2 meters	(3.9 feet)

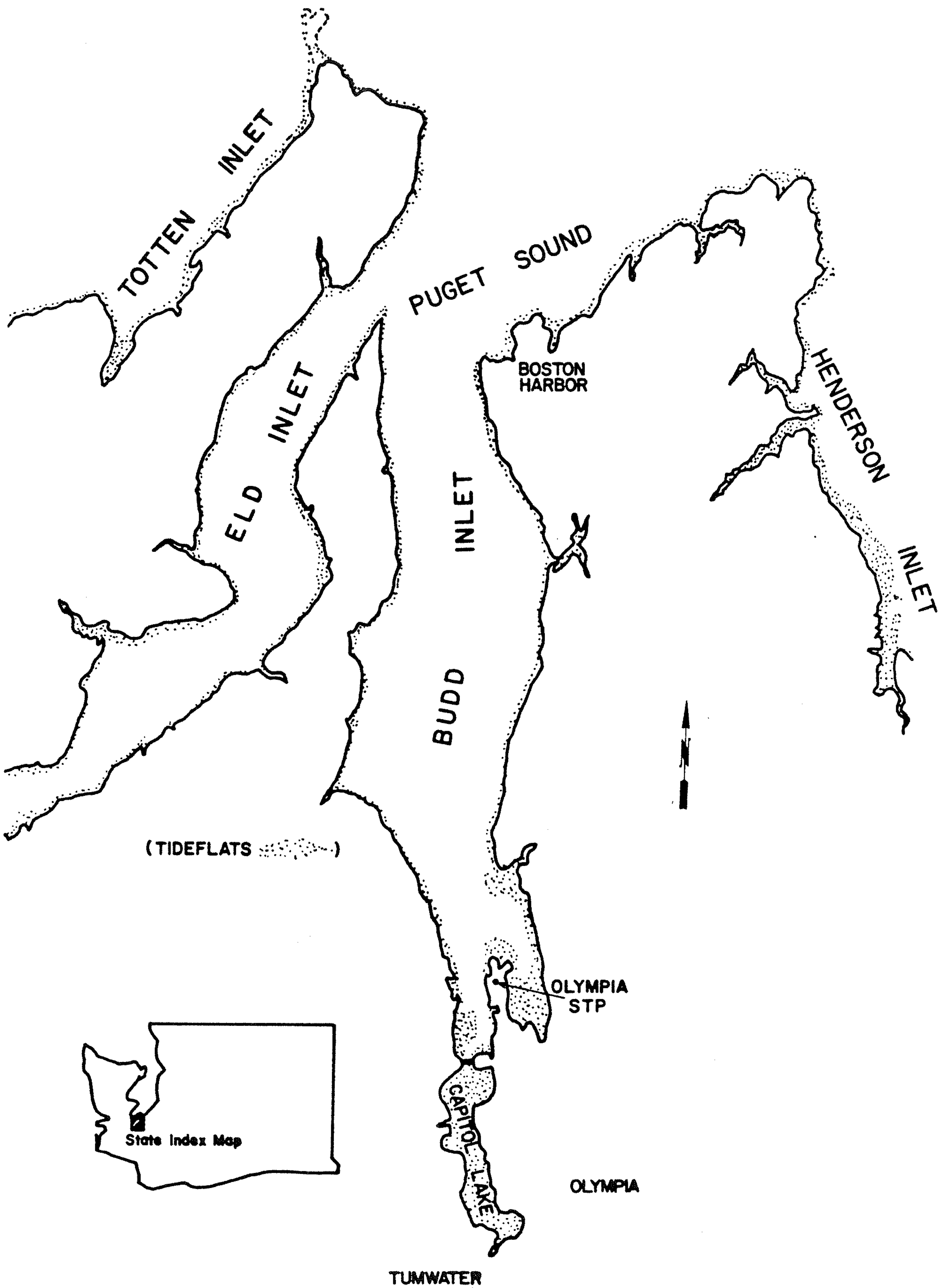

Figure 1. Map of Budd Inlet and Surrounding Area.

METHODS AND MATERIALS

MORPHOMETRY AND HYDROLOGY

The surface area and volume of Budd Inlet was determined using U. S. Coast and Geodetic Survey Nautical Chart No. 6462 (NOAA, 1972). The northern boundary was arbitrarily set as a straight line extending from Cooper Point to Dover Point. Mean high water (MHW), mean lower low water (MLLW), and the 1, 2, 3, 5, and 10 fathom contour lines on the chart were utilized. Two additional contour lines were drawn at 15 and 18.5 fathoms. The surface area for each contour level was determined using a compensating polar planimeter (Keuffel and Esser N.O. 620015). Volume determinations for each depth interval were calculated according to Welch (1948). Summation of the volumes for each stratum produced the total volume for the inlet.

WATER QUALITY SURVEYS

Point Source Inventory

National Pollutant Discharge Elimination System (NPDES) permits were reviewed to determine major dischargers to Budd Inlet. The only point source with a substantial discharge was the Olympia sewage treatment plant. Thirteen combined storm sewer overflow sites were monitored during the study period (Figure 2). Four additional stations were established on feeder streams to determine the contribution of these freshwater sources. These streams included the Deschutes River and Percival, Moxlie, and Ellis creeks. Detailed station descriptions are presented in Appendix I.

Discharge rates for the Olympia STP were obtained from the plant's monthly monitoring reports. Deschutes River discharge measurements were made at the USGS gaging station at Tumwater. Discharge data for Percival Creek were collected at the footbridge near Percival Cove (DOE, unpublished data). These two flow records were used to estimate Capitol Lake discharge. Depending on flow, discharge rates for other monitored point source stations were measured either by a Marsh-McBurney magnetic flow meter or the bucket/stopwatch method. Climatological data for the Olympia area was obtained from National Oceanic and Atmospheric Administration records.

Dissolved oxygen was measured by the azide modification of the Winkler method. Temperature readings were taken in the field. Laboratory samples were collected and analyzed for the following: total and fecal coliform bacteria; pH; turbidity; conductivity; nitrite-nitrogen; nitrate-nitrogen; ammonia-nitrogen; orthophosphate-phosphorus; total phosphate-phosphorus; total solids; total suspended solids; chemical oxygen demand (COD); and biochemical oxygen demand (BOD_5) (A.P.H.A., 1975).

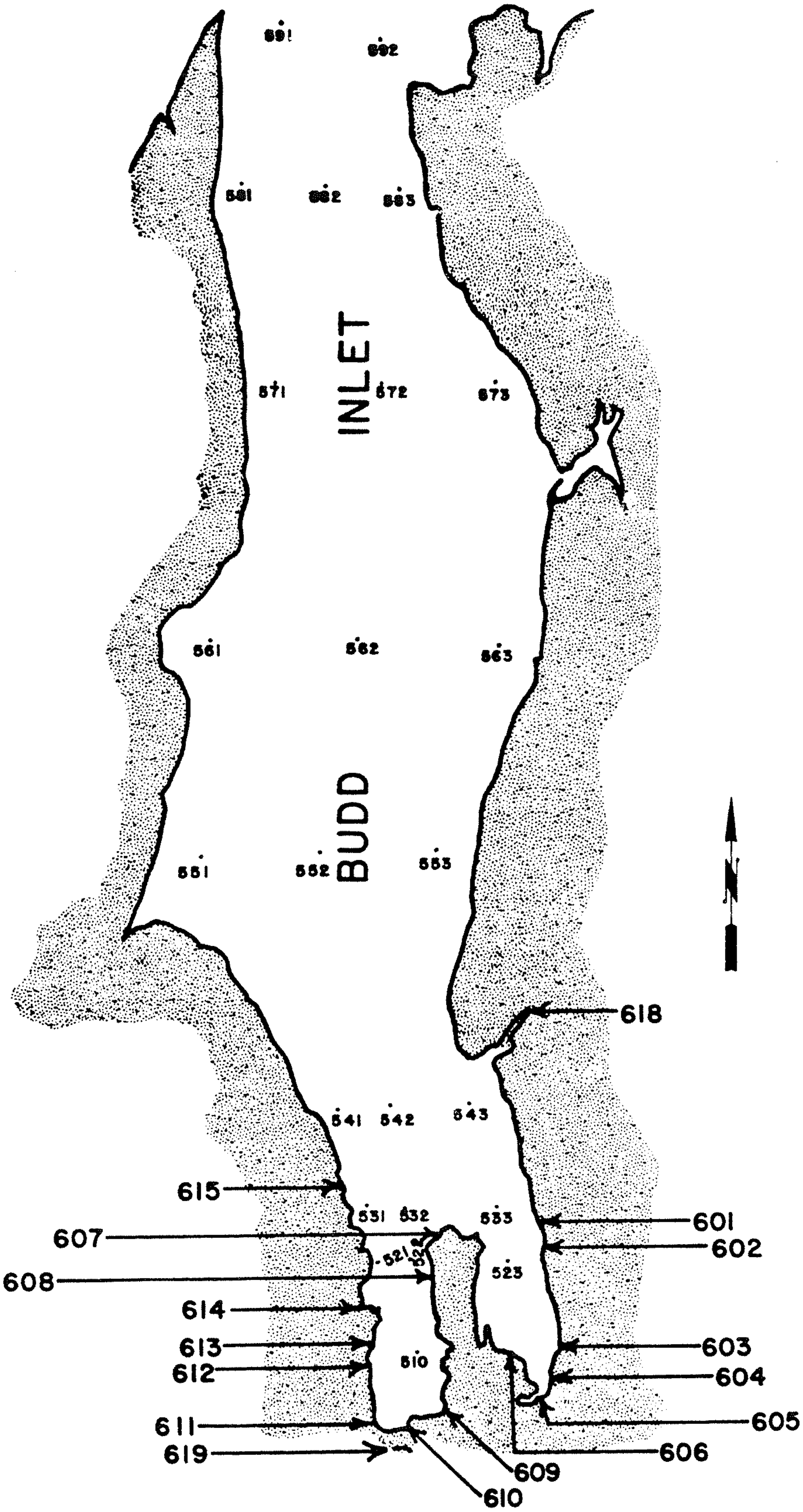

Figure 2. Map of Study Area Detailing Receiving Water and Point Source Sampling Stations.

Loading rates for point source and stream stations were computed either as pounds per day or in the case of fecal coliform loading, as number of bacteria or organisms per day. The loading rates were computed by multiplying the mean concentration by the mean discharge.

Receiving Waters

Twenty-four stations on nine transects were initially sampled to determine general water quality characteristics of the inlet (Figure 2). Review of data collected from the 10 stations south of Priest Point Park (Class B waters) showed the greatest variability in water quality between stations. The 14 stations north of Priest Point Park (Class A waters) had similar water quality; therefore, 12 of these were eliminated from further sampling. The following 10 stations were sampled during the remainder of the study: 510, 521, 522, 523, 531, 532, 533, 542, 562, and 592. Detailed station descriptions are presented in Appendix I.

Monthly sampling supplemented by surveys during storm events was conducted during September 1976 through February 1978. Twenty-one sampling runs were made during this period. Sampling times coincided with low or lower low tide stages for the following reasons: (1) the inlet had the lowest dilution volume; (2) subsurface discharges were exposed; and (3) Capitol Lake was discharging.

Five physical and chemical parameters were measured *in situ* at each station. A Beckman Electrodeless Induction Salinometer was used to measure salinity, conductivity, and temperature at surface, half-meter, one-meter intervals to 5 meters, 10 meters, 15 meters, and near bottom. Dissolved oxygen was measured either by the azide modification of the Winkler method or by an International Biophysics Corporation (IBC) dissolved oxygen probe. Transparency was determined with a secchi disk. The euphotic zone depth was estimated by multiplying 2.7 times the secchi disk depth.

At each station, laboratory samples were collected at three depths (surface, mid-depth, and bottom) and analyzed for the following: total and fecal coliform bacteria; pH; turbidity; nitrite-nitrogen; nitrate-nitrogen; ammonia-nitrogen; orthophosphate-phosphorus; and total phosphate-phosphorus. Chlorophyll *a* and pheophytin *a* samples were collected at the surface, mid-depth, and bottom of the euphotic zone.

DISSOLVED OXYGEN MODEL

The model used in this study was a one-dimensional, steady-state model for predicting dissolved oxygen concentrations (O'Connor and Thomann, 1971). A one-dimensional model describes the hydrodynamic and mass transfer processes proceeding in a horizontal direction. This allows for a simplistic mathematical approach in comparison to other multi-dimensional models. Steady-state refers to the time-averaging concept in model computations. In the case of Budd Inlet, the time factor was based on the replacement time of the inlet. This is the number of tidal cycles required to replace the inlet with "new" water.

This model used first-order reaction rates based on two input categories: sources and sinks. These refer to the various reactions and wastewater inputs which affect the concentration of dissolved oxygen in the estuary. Dissolved oxygen sources include Puget Sound waters which enter Budd Inlet, freshwater input from Capitol Lake (principal source), and surface reaeration. Reaeration coefficients used in model computations were corrected for wind velocity (Banks and Herrera, 1977). Point source BOD loading and phytoplankton decomposition were used as DO sinks (Welch, 1969). Oxygen uptake by decaying phytoplankton was estimated from pheophytin _a_ concentrations. Planktonic oxygen production and respiration were not included.

The model was developed from water quality data collected at six mid-channel stations, each representing one segment of the inlet. These stations were 510, 522, 532, 542, 562, and 592 (Figure 2). Volume-averaged salinity and temperature were then computed for the six segments. These data were used in the model calculations for saturated dissolved oxygen concentrations.

To achieve the degree of sensitivity necessary to detect subtle changes in dissolved oxygen levels, the inlet was further subdivided into a total of 15 segments. Salinity and temperature values for those segments without data were obtained by extrapolation. The new segments were created in the lower inlet where the greatest salinity and temperature changes occurred. A schematic drawing of the model and the physical dimensions of the 15 segments are presented in Appendix II.

RESULTS AND DISCUSSION

MORPHOMETRY AND HYDROLOGY

The surface areas at MHW and MLLW were 22.1 Km^2 and 19.5 Km^2, respectively (Table 2). The difference between these values (2.6 Km^2) is primarily due to the large tidal flat area exposed in the southern portion of Budd Inlet during low tide. The total volume in Budd Inlet at MHW and MLLW was estimated at 2.68×10^8 M^3 and 1.82×10^8 M^3, respectively. The difference between these two figures represents the volume of water involved in a mean tidal exchange of 8.60×10^7 M^3, or about 32 percent of the total basin volume. Data collected during this study compare favorably with data collected by two previous investigators (McLellan, 1954; Collias, 1970) (Table 2). The intertidal volume for Budd Inlet for any tide cycle can be determined by subtracting the values obtained on the y-axis in Figure 3.

Using the mean tidal exchange (32 percent) as a flushing rate measurement, Budd Inlet replaces itself in 3.1 tidal cycles (Table 2). The same calculation for all of Puget Sound yields 25.3 cycles (Duxbury, Friebertshauser, and Richey, 1972). The high rate of exchange for Budd Inlet waters is attributed to the lack of an entrance sill, a wide mouth opening directly into a large, well-mixed tidal channel, and the lack of turbulent mixing in the lower inlet, thus allowing freshwater to escape in the surface layer (Olcay, 1959). However, northerly winds which occasionally prevail for considerable periods during the summer months tend to hold surface waters in the inlet, decreasing the flushing rate (ibid, 1959).

Table 2. Comparison of morphological and hydrological data collected on Budd Inlet by McLellan, Collias, and Kruger.

	McLellan (1954)	Collias (1970)	Kruger (1979)
Surface Area ($1 \times 10^7 M^2$)			
at MHW	2.26	2.65	2.21
at MLLW	1.86	2.23	1.95
Volume ($1 \times 10^8 M^3$)			
at MHW	2.34	2.80	2.68
at MLLW	1.63	1.79	1.82
Mean Depth (Meters)	8.8	8.0	9.3
Intertidal Volume ($1 \times 10^8 M^3$)	0.71	1.01	0.86
Percent Intertidal Volume(1)	30%	36%	32%
Flushing Time in Tide Cycles(2)	3.3	2.8	3.1

(1) $\frac{\text{Intertidal Volume}}{\text{Basin Volume}} \times 100$

(2) $\frac{\text{Basin Volume}}{\text{Intertidal Volume}}$

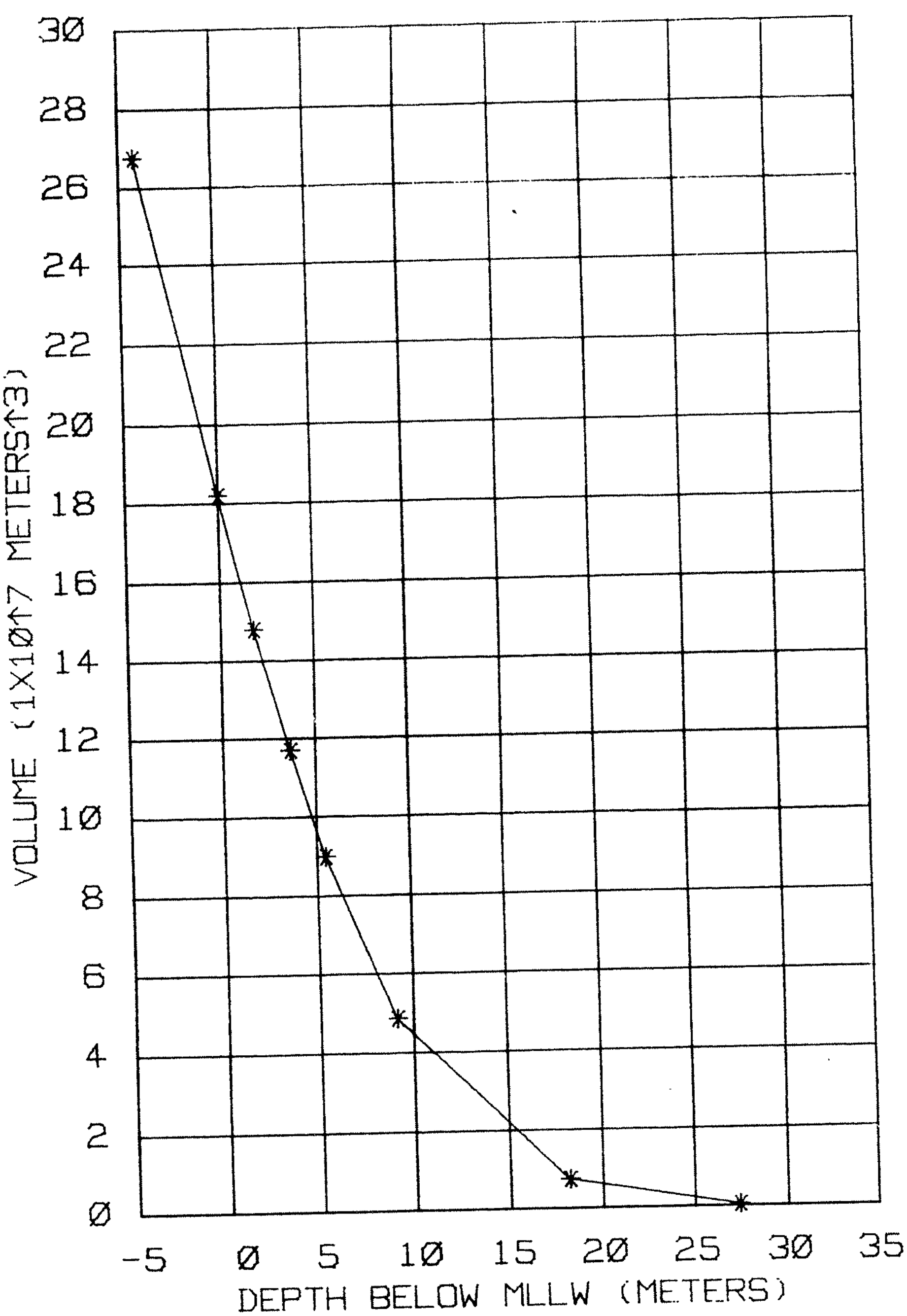

Figure 3. Volume of water (m^3) in Budd Inlet according to tidal height.

Flushing "efficiency", as defined by Friebertshauser and Duxbury (1972), is the ability of a basin to completely flush itself with new water. Flushing efficiency was not determined for Budd Inlet. However, the average monthly flushing efficiency of southern Puget Sound has been estimated to be 54 percent (ibid, 1972). Therefore, it would take approximately two months for southern Puget Sound to completely flush itself.

WATER QUALITY SURVEYS

Point Source Inventory

Precipitation was below normal throughout the study period. Thus, data collected from 13 overflows were not representative of typical wet weather periods and may have resulted in underestimating their loading rates. Based on results from 14 point source sampling runs, each source was ranked by the mean instantaneous discharge (Table 3). Capitol Lake, Moxlie Creek, Olympia STP, and Ellis Creek contributed 99 percent of the total freshwater inflow to Budd Inlet. Of these, Capitol Lake contributed 90 percent. The remaining sources were observed to have such low and intermittent flow that they were considered to have little importance and will not be discussed further.

Of the freshwater inputs, Olympia STP effluent was the major source of orthophosphate-phosphorus loading (82 percent) to the inlet. Capitol Lake discharge, on the other hand, was the major source of nitrate-nitrogen (80 percent). However, these two sources did not significantly increase nutrient levels in Budd Inlet (to be discussed).

The Olympia STP effluent contributed 81 percent of the BOD discharged to the inlet from monitored point source stations (Table 4). Mean BOD loading from the treatment plant during the study was 35,205 lbs. per day. This is below the plant's monthly NPDES permit limitation of 55,000 lbs. per day. Subtracting the small amount of DO in the effluent, the mean dissolved oxygen deficit created by the Olympia STP averaged 35,000 lbs. per day during the study. Capitol Lake, on the other hand, contributed 93 percent of the dissolved oxygen (8,340 pounds per day) to the inlet. Quantifying all point source BOD and DO inputs, an average net loss of 26,200 pounds per day DO was attributed to the monitored point sources.

Capitol Lake, Moxlie Creek, and the Olympia STP each contributed approximately one-third of the fecal coliform loading to Budd Inlet (Table 4). Moxlie Creek discharge had essentially the same impact on fecal coliform loading to Budd Inlet as the Olympia STP chlorinated effluent. Reviewing the LOTT facilities plan, five combined storm sewer overflows enter into this creek (KCM, 1976). Through improved disinfection of the STP effluent and complete elimination of all sanitary inputs to Moxlie Creek, a 50 percent or greater reduction in fecal coliform loading may occur. During a normal rainfall year, it is possible that bacterial reductions would be even greater.

Table 3. Rank of mean instantaneous discharge (MGD) of all point source stations and the number of occurrences during the study period (9/76 - 2/78).

Rank	Station		Mean Instantaneous Discharge (MGD)	Number of Occurrences
1	619	Capitol Lake	186.40	14
2	605	Moxlie Creek	8.78	14
3	607	STP Outfall	6.95[1]	14
4	618	Ellis Creek	3.77	14
5	601	Joy & East Bay Drive	1.29	1
6	614	Browne & West Bay Dr.	0.20	2
7	602	San Francisco & East Bay Dr.	0.16	8
8	612	Jackson & West Bay Drive	0.11	2
9	604	Thurston & East Bay Drive	0.07	2
10	611	Olympia Way & 4th	0.06	1
11	615	West Bay Marina Pump Sta.	0.03	7
12	603	Glass & East Bay Drive	----	0
	606	Olympia STP Emergency Bypass	----	0
	608	Olympia STP Bypass	----	0
	609	State & Water	----	0
	610	Brenner & 4th	----	0
	613	Foote & Jackson	----[2]	1

(1) Mean Monthly Discharge Taken from STP Monitoring Reports.
(2) Insufficient Flow Measurements Collected.

Table 4. Mean loading rates for major point source stations having greater than 99% of total freshwater inflow into Budd Inlet during the study period (9/76 - 2/78).

Station	Flow (MGD)	% of Total	$O\text{-}PO_4\text{-}P$ (lbs/day)	% of Total	$NO_3\text{-}N$ (lbs/day)	% of Total	BOD_5 (lbs/day)	% of Total	DO (lbs/day)	% of Total	Fecal[1] (org/day)	% of Total
619 Capitol Lake	186	90	47	16	296	80	7,778	18	16,115	93	1.89×10^{11}	31
605 Moxlie Creek	9	4	6	2	45	12	306	1	680	4	1.87×10^{11}	30
607 STP Effluent	7	3	244	82	7	2	35,205	81	144	1	2.32×10^{11}	37
618 Ellis Creek	4	2	1	0	23	6	147	0	324	2	1.01×10^{10}	2
Totals	206		298		371		43,436		17,245		6.18×10^{11}	

[1] Geometric Mean.

Receiving Waters

In general, water quality in Budd Inlet decreased in a southerly direction from Boston Harbor (Station 592) to Capitol Lake (Station 510). Dissolved oxygen, dissolved oxygen saturation, pH, and transparency decreased toward Capitol Lake (Table 5). Temperature and fecal coliform bacteria showed corresponding increases.

Freshwaters discharged from Capitol Lake into the inlet initially remained as a distinct surface layer approximately one meter deep. This layer became well mixed with the marine waters of Budd inlet within a short distance, with the estuary becoming essentially homogenous in terms of salinity north of Priest Point Park. This freshwater layer was affected only slightly by tide stage (Figure 4). Lateral and horizontal freshwater distribution patterns at the surface and at one meter did not show any well-defined freshwater surface currents (Figure 5). In addition, no major seasonal variations were observed in the mid-channel salinity profiles (Figure 6).

Although Capitol Lake was the major contributor of dissolved oxygen to Budd Inlet, it appears current management practices for controlling lake water quality may at times contribute to decreased water quality in southern Budd Inlet. During late summer, Capitol Lake is periodically drawn down to flush the algal crop from the lake. Closure of the tidal gates for several days to raise the lake level would remove the major source of dissolved oxygen (8,340 pounds per day) to the inlet. This practice may be a factor in lowering DO concentrations to critical levels. Even a small continuous discharge from the lake during all phases of the flushing process may add sufficient dissolved oxygen to prevent fish mortalities near Capitol Lake Dam (Earl Finn, personal communication).

It appears nutrient loading contributed by all of the identified point sources is insignificant when compared to the nutrient supply existing in the water column. Puget Sound waters entering Budd Inlet are abundant in nutrients throughout the year (Figure 7). Annual cyclic nutrient concentrations determined for Budd Inlet during the study were similar to those observed in northern Puget Sound (Winter, 1975). Primary productivity in Budd Inlet does not appear to be nutrient limited. The main factor initiating phytoplankton blooms in Budd Inlet and most of Puget Sound is light availability. Therefore, in the case of the Olympia STP, the addition of nutrient removal would not significantly reduce nutrient levels and phytoplankton blooms in Budd Inlet.

Low DO concentrations were measured in Olympia Harbor during September 1976 and again the following late summer. Dissolved oxygen data collected near the STP outfall (Stations 522 and 532) did not show an appreciable decline in DO levels compared to the harbor in general. The periodic DO sags coincided with other factors such as Capitol Lake flushing, indigenous phytoplankton blooms, and optimal weather conditions (to be discussed later). Therefore, it appears moving the existing outfall into deeper waters would not significantly increase dissolved oxygen concentrations in southern Budd Inlet.

Table 5. Range and mean water quality data for selected mid-channel stations over all depths and all dates.

Station	Temp (°C)	Salinity (0/00)	DO (mg/l)	Computed[1] DO Sat. (%)	Fecal[2] Coliform (#/100 ml)	pH	NO_3-N (mg/l)	O-PO_4 (mg/l)	Transparency (m)
	6.9-23.2	.8-34.0	1.9-12.5		2-10,000	5.2-8.4	.01-.44	.02-.16	.6-3.4
510	11.6	26.1	7.7	83	22	7.6	.23	.06	1.6
	6.5-21.0	1.7-35.5	1.8-13.2		2-670	7.3-8.4	.01-.45	.02-.18	.6-3.4
522	11.2	27.6	7.6	82	15	7.7	.22	.07	1.6
	6.7-21.9	6.5-34.8	1.9-11.4		2-400	7.3-8.1	.02-.43	.03-.14	1.0-2.9
532	11.0	28.3	8.1	87	12	7.7	.24	.07	1.7
	6.7-24.1	8.8-34.1	1.9-16.9		2-1300	7.2-8.0	.01-.44	.02-.29	1.0-5.2
542	11.2	29.4	8.4	91	10	7.7	.22	.07	2.2
	6.2-25.8	22.1-34.4	5.5-12.9		1-400	7.6-8.9	.02-.44	.02-.19	1.0-6.7
562	10.9	30.0	9.0	98	3	7.8	.26	.06	3.2
	6.2-19.2	27.8-34.6	7.5-12.3		1-26	7.6-8.9	.02-.45	.02-.11	3.0-7.2
592	10.9	30.7	9.2	100	2	7.9	.28	.06	4.9

[1]Computed from mean temperature, salinity, and DO data.

[2]Geometric Mean

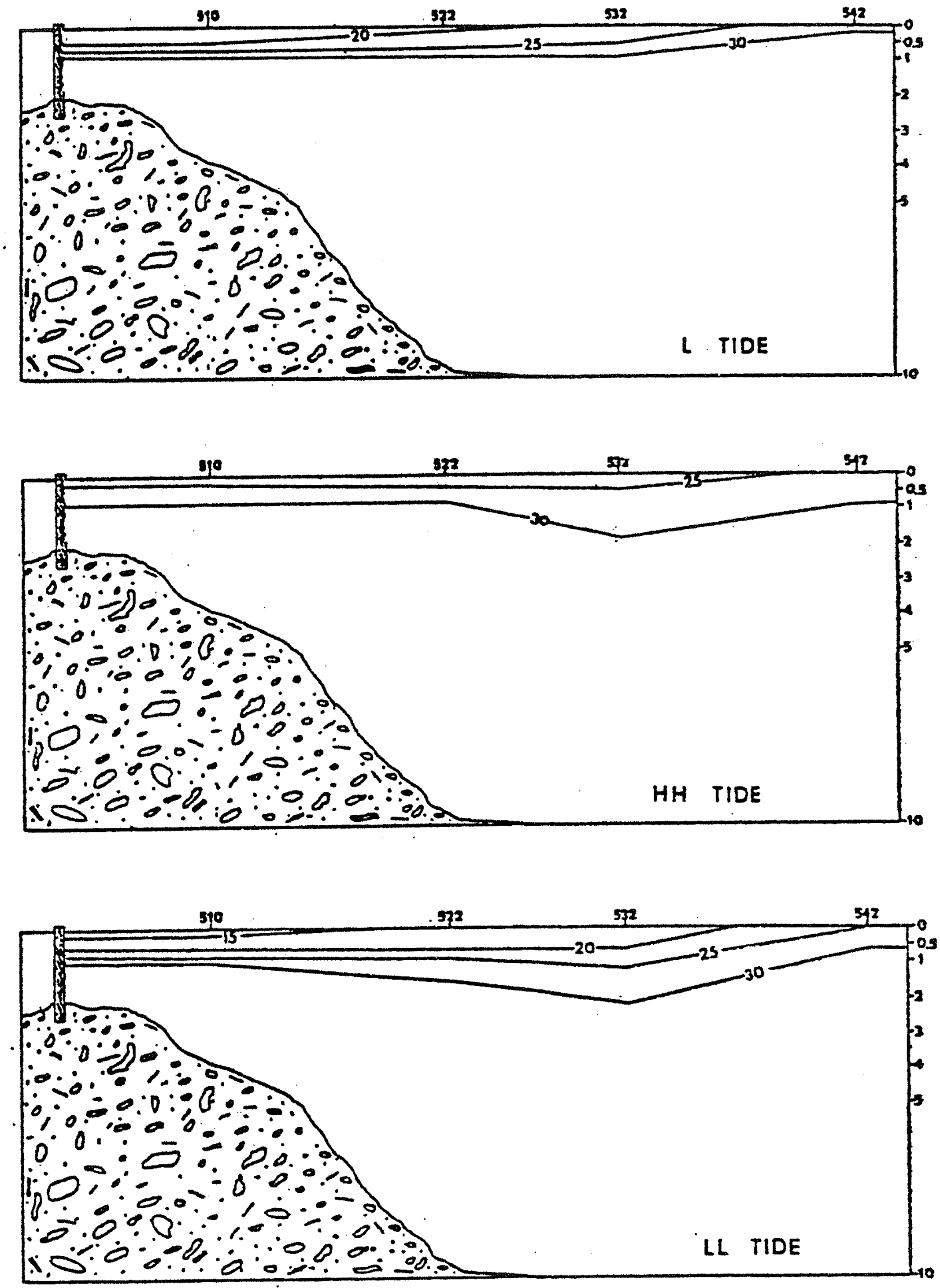

Figure 4. Vertical salinity profiles for southern Budd Inlet during one tidal cycle (2/6/78).

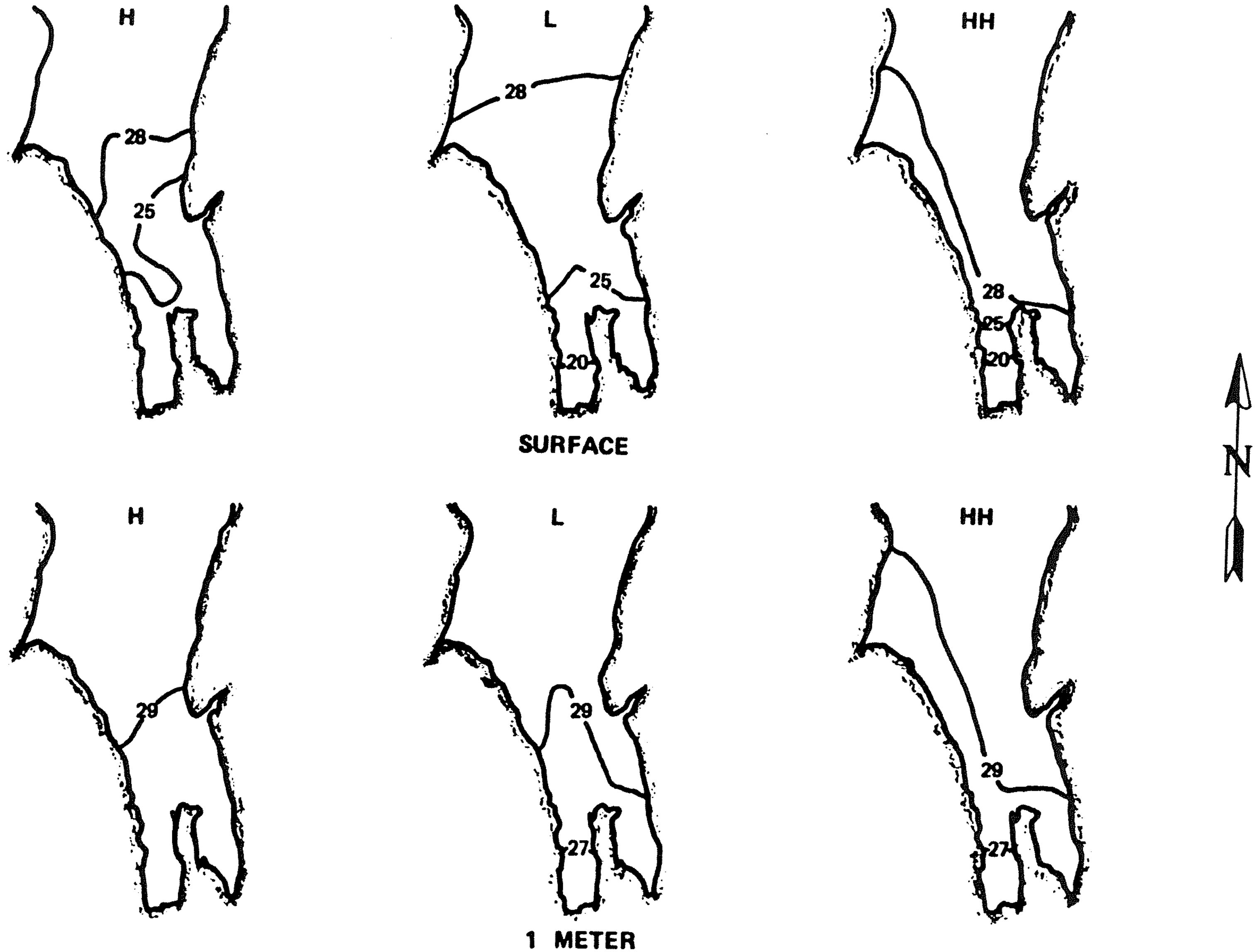

Figure 5. Lateral and horizontal salinity distribution for southern Budd Inlet at surface and 1 meter depth (2/6/78).

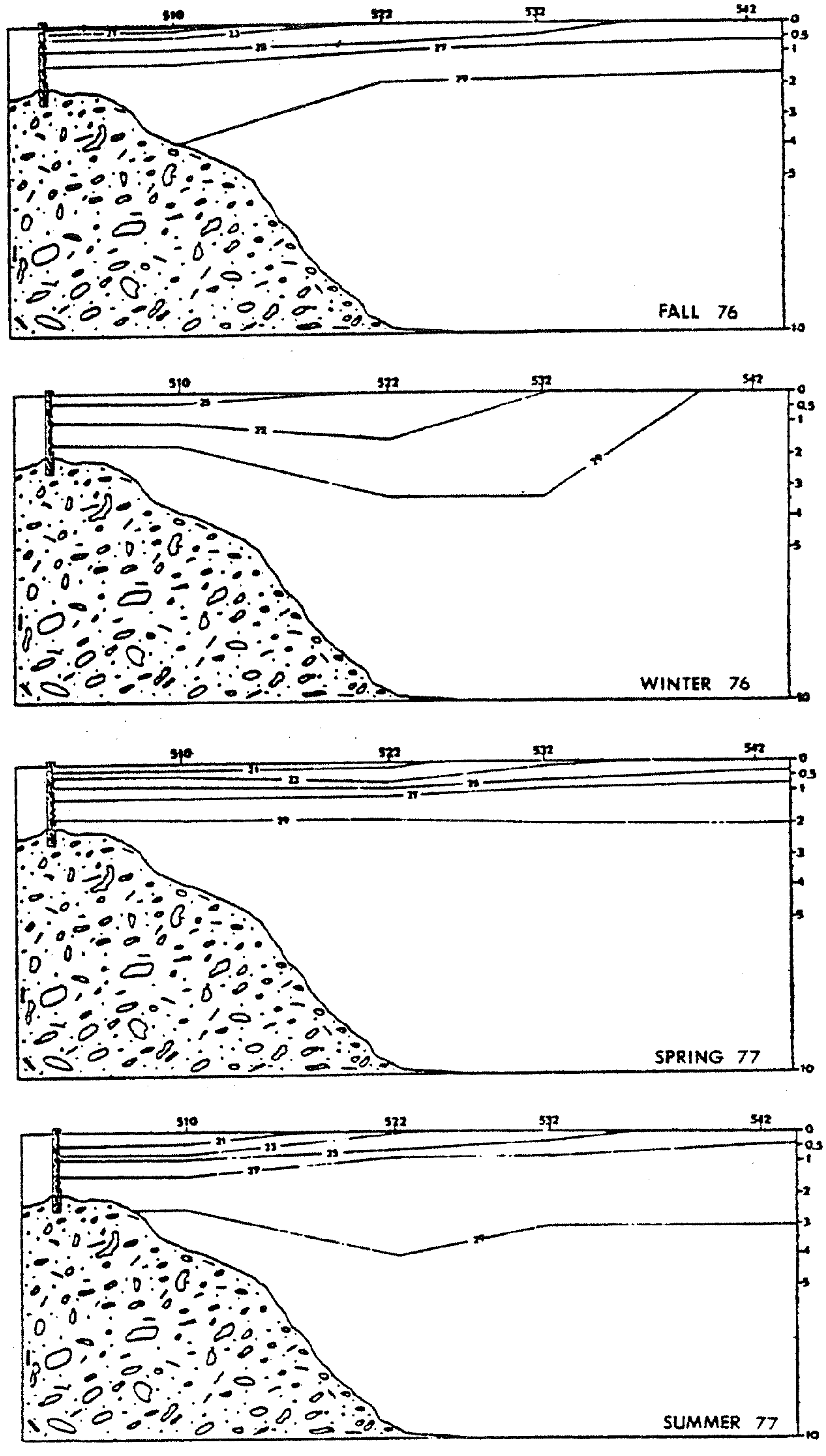

Figure 6. Seasonal salinity profiles for southern Budd Inlet.

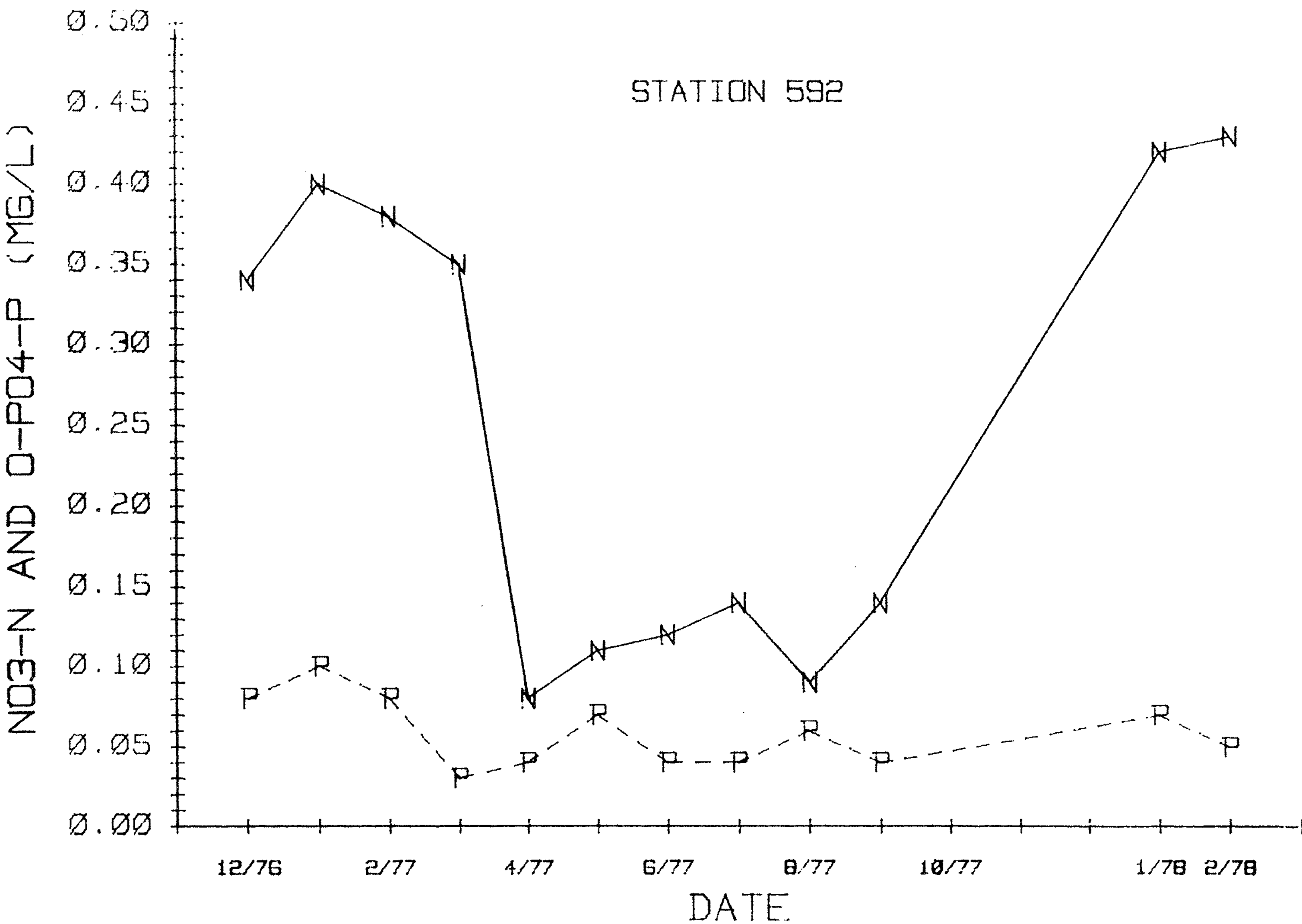

Figure 7. Nitrate-nitrogen and orthophosphate-phosphorus concentrations (mg/l) in Budd Inlet during the study period at station 592.

Fecal coliform densities throughout the study were higher in the port area than in the outer harbor (Figure 8). This is what would be expected because of the number of point sources located around the southern end of Budd Inlet. The rapid decline in fecal densities north of Priest Point Park coincides with the water quality class designation established by the Department of Ecology. From the data it appears that Budd Inlet is properly classified at this time. However, assuming a substantial reduction in bacterial densities will occur due to the treatment plant upgrade and sewer overflow elimination, the inner harbor area may, in the future, change from Class B to Class A marine waters.

Data was collected throughout a complete tidal cycle in February 1978 to determine if fecal coliforms were concentrating in the lower inlet during incoming tides. Sampling was initiated at low tide and ended at lower low tide. A pooling or concentrating of surface and depth-averaged fecal coliforms at high slack tide did not occur (Figure 9). If anything, fecal coliform counts may have increased slightly during the lower low slack tide, with surface densities usually being higher than depth-averaged concentrations.

Little information is available on bacterial die-off and regrowth of fecal coliforms in marine waters. Without these two rates as well as dilution and diffusion data, it would be difficult to trace bacterial levels in the receiving waters to a point source.

A source of fecal coliforms not accounted in this study was from the indigenous waterfowl populations. Some 3.9×10^{10} fecal coliforms per year could be contributed by a single bird (CH_2M Hill, 1978). Considering the large number of aquatic birds in Budd Inlet, it is surprising that bacterial densities are not higher.

DO Problems in Lower Budd Inlet

The southern end of Budd Inlet has historically experienced late summer low DO concentrations (Cregg, 1975; Stanley and Cloud, 1975). Throughout this investigation DO levels in Olympia Harbor were generally lower than those observed north of Priest Point Park. The summer of 1977 was the worst case on record of the existing DO problem in lower Budd Inlet. This condition was also documented by the Army Corps of Engineers' sampling during 1977 (unpublished) and DOE routine monitoring data (Figures 10 through 12). These data show that during August a massive dissolved oxygen sag extended from Capitol Lake out 5.5 kilometers (3.4 miles) into the inlet (Figure 11) and lasted for nearly six weeks. Mean DO values below 1 meter depth ranged from 0.06 to 2.3 mg/l during this period.

The DO sag in lower Budd Inlet during the summer of 1977 coincided with an extensive dinoflagellate bloom throughout the inlet. Dinoflagellates are commonly referred to as red tide organisms, a good description. In bloom proportions the water turns pink to red to rust brown in color

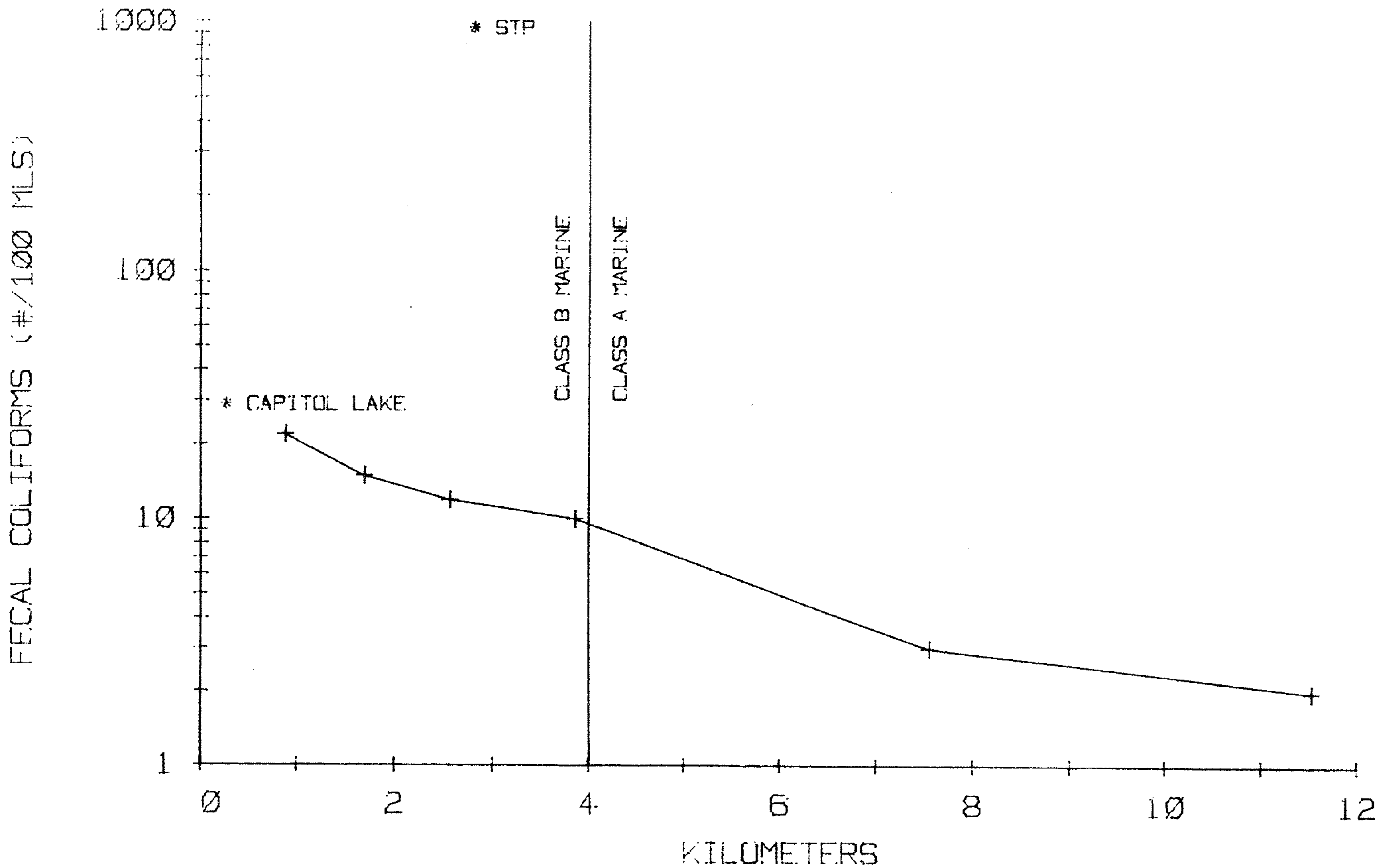

Figure 8. Geometric mean fecal coliform densities in Budd Inlet during the study period (9/76 - 2/78).

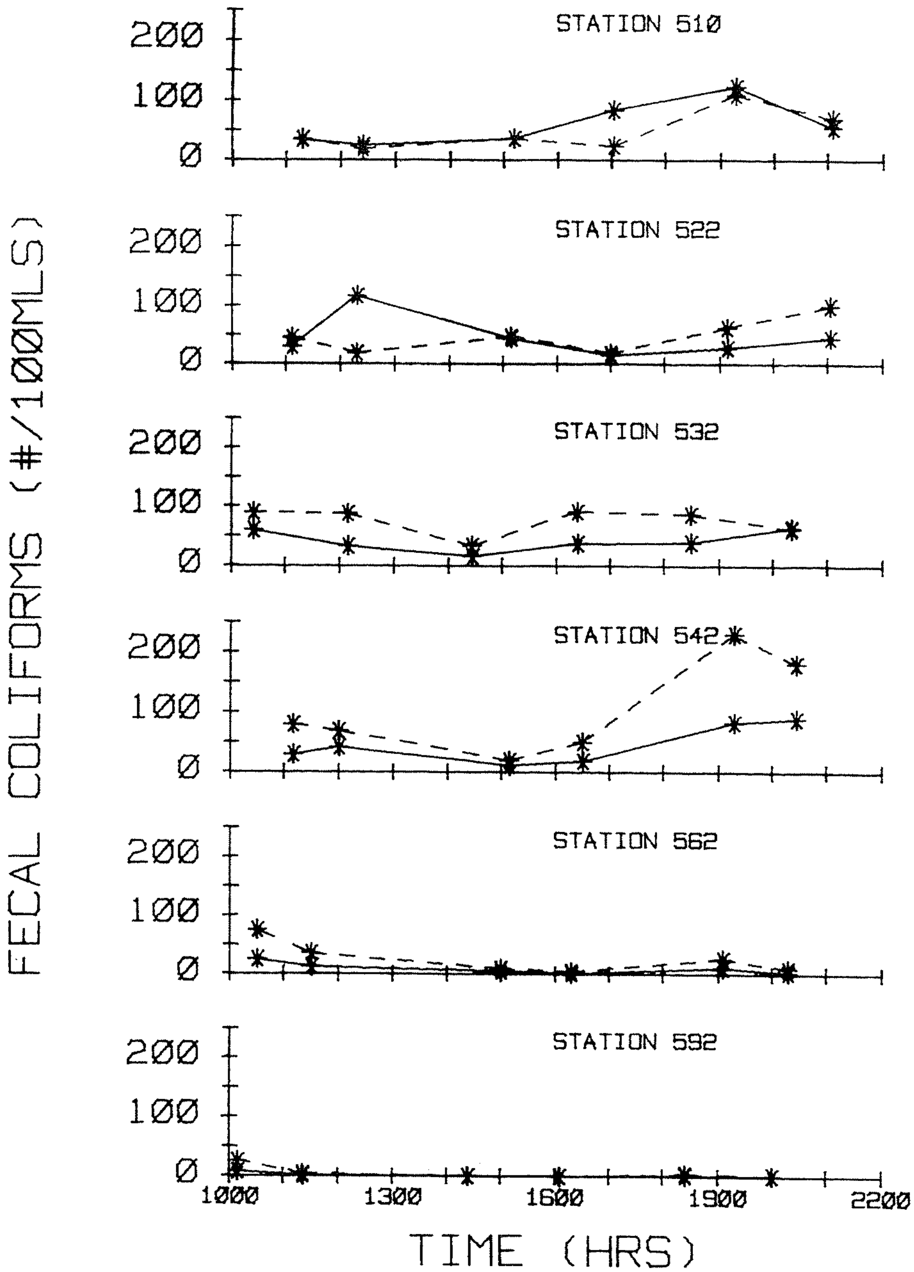

Figure 9. Surface (---) and depth-averaged (——) fecal coliform densities in Budd Inlet over one complete tidal cycle (2/6/78).

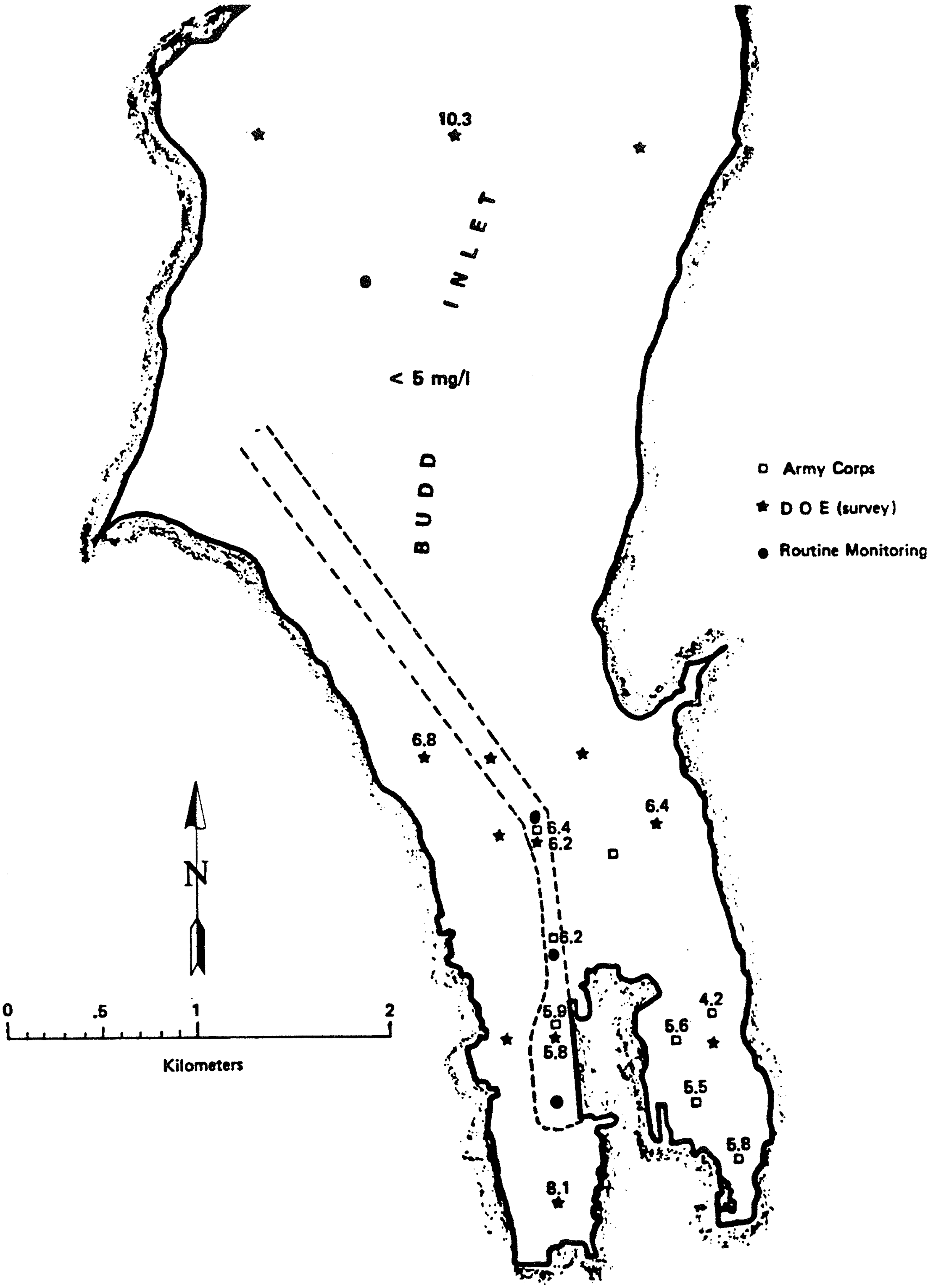

Figure 10. Mean dissolved oxygen concentrations (mg/l) for depths below 1 meter in lower Budd Inlet during low tide (7/18-24/77).

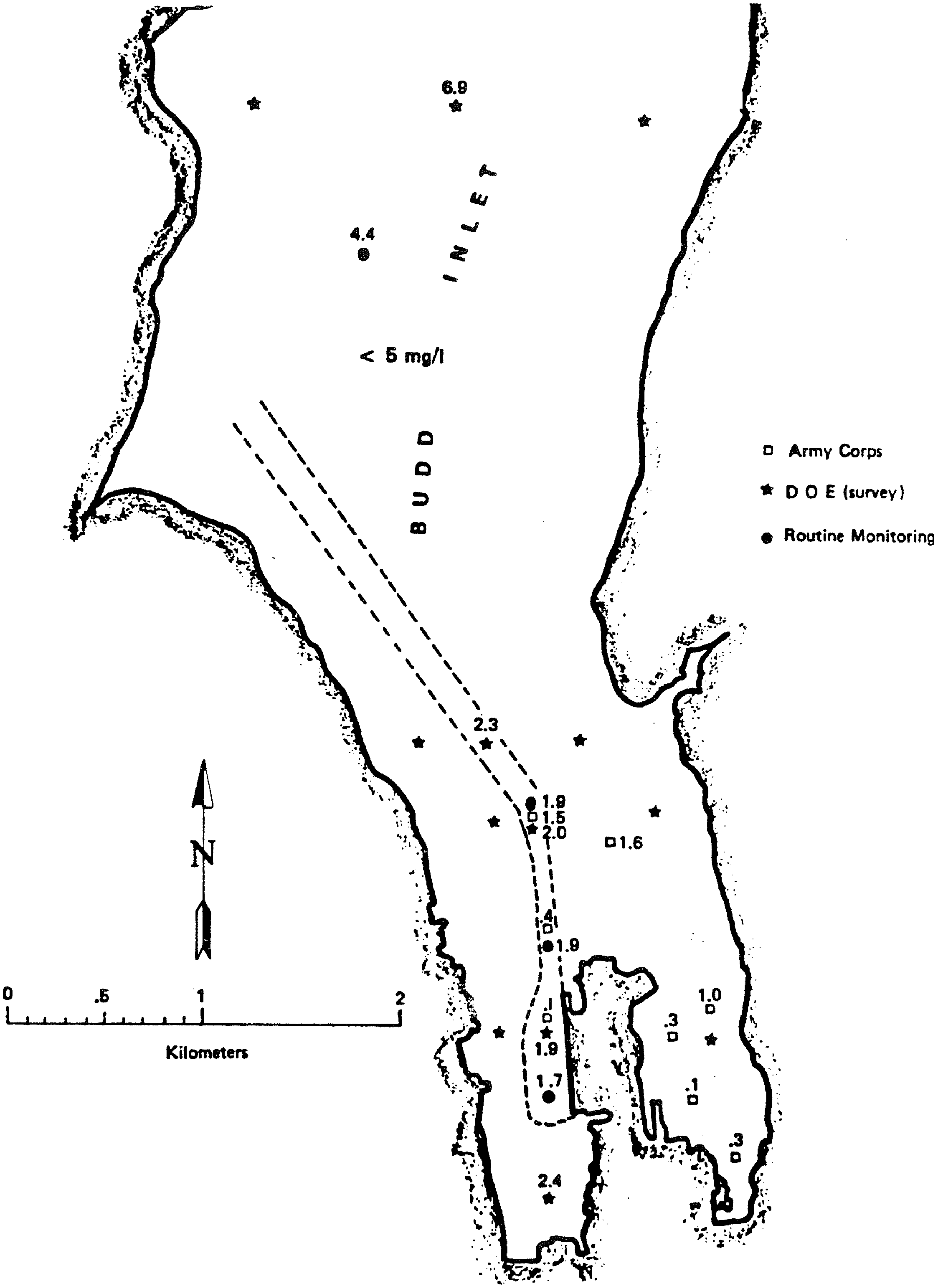

Figure 11. Mean dissolved oxygen concentrations (mg/l) for depths below 1 meter in lower Budd Inlet during low tide (8/16-18/77).

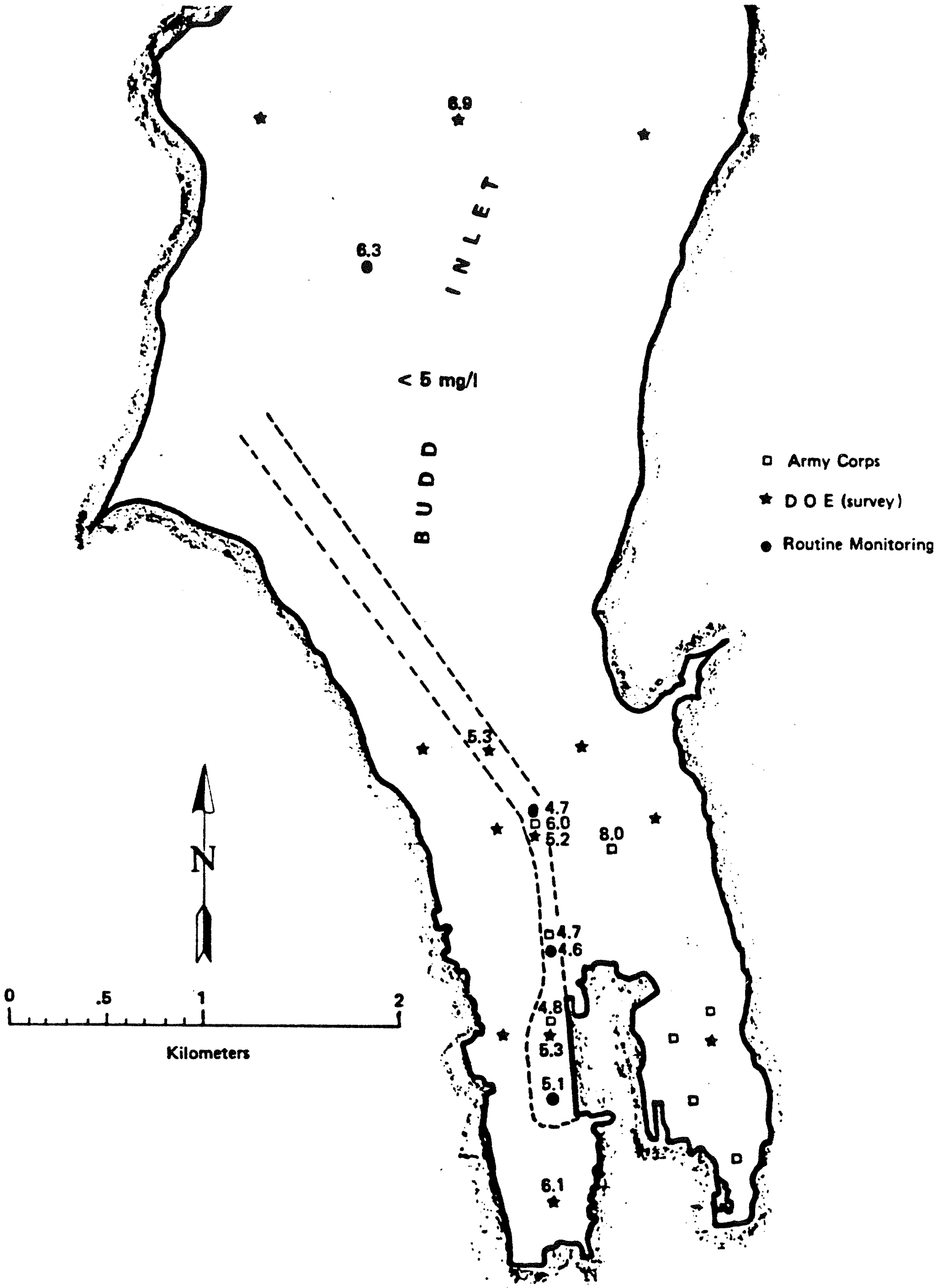

Figure 12. Mean dissolved oxygen concentrations (mg/l) for depths below 1 meter in lower Budd Inlet during low tide (9/12-15/77).

which is aesthetically unpleasing to the eye. The two dominant species during the bloom were *Ceratium fusus* and *Noctiluca scitillans*. Fortunately, these species are relatively non-toxic. A surface grab sample collected at station 522 during the peak bloom was estimated to contain greater than 10,000,000 cells per liter, a concentration higher than what can be cultured in the laboratory (Augustine Chan, personal communication). The disproportionately high phytoplankton densities resulted from minimal cloud cover, extended warm weather, and north winds concentrating the standing crop into the southern end of the inlet.

Chlorophyll data collected in lower Budd Inlet during August indicated the phytoplankton bloom was past the growth phase as evidenced by the high concentration of pheophytin a (Figure 13). Pheophytin a is a breakdown product of chlorophyll a. Greater chlorophyll a concentrations were present during May and September, indicating a growing bloom and DO concentrations throughout the inlet were substantially higher. Other investigators have found that large respiring and decomposing phytoplankton blooms can significantly deplete dissolved oxygen in the water column (Welch, 1969; Nece, *et al.*, 1975). Organic matter contributed by sinking (dead) phytoplankton cells was considered to be an important source of oxygen uptake.

The ratio of the optical densities of chlorophyll a to pheophytin a is also indicative of the physiological state of a phytoplankton population. Ratios ranged between 1.0 and 1.7. Water samples having ratios approaching 1.7 are considered to be in excellent physiological condition, while ratios nearing 1.0 are in poor physiological condition. August ratios were the lowest, ranging from 1.20 to 1.35 in the inner harbor where the severe DO sag was observed (Figure 14). June ratios were the highest, ranging from 1.53 to 1.59 with September ratios fluctuating from 1.35 to 1.52. DO levels during these months were substantially higher.

DISSOLVED OXYGEN MODEL PREDICTIONS

Dissolved oxygen predictions for June, August, and September 1977 closely approximated observed DO concentrations in Budd Inlet (Figure 15). The variance of the predicted values from those observed appeared to be due to phytoplankton oxygen production (source) and respiration (sink) which were not included in the model. The June and September phytoplankton communities were in better physiological condition than the August bloom. Observed DO concentrations were higher these months than predicted values. During August, observed DO concentrations were lower than predicted values. It appears that during August, respiration and decomposition by planktonic organisms may have exceeded oxygen production. This is supported by the greater amount of pheophytin a during the August bloom as well as a self-shading effect (decreasing photosynthetic activity) caused by large algal cell concentrations.

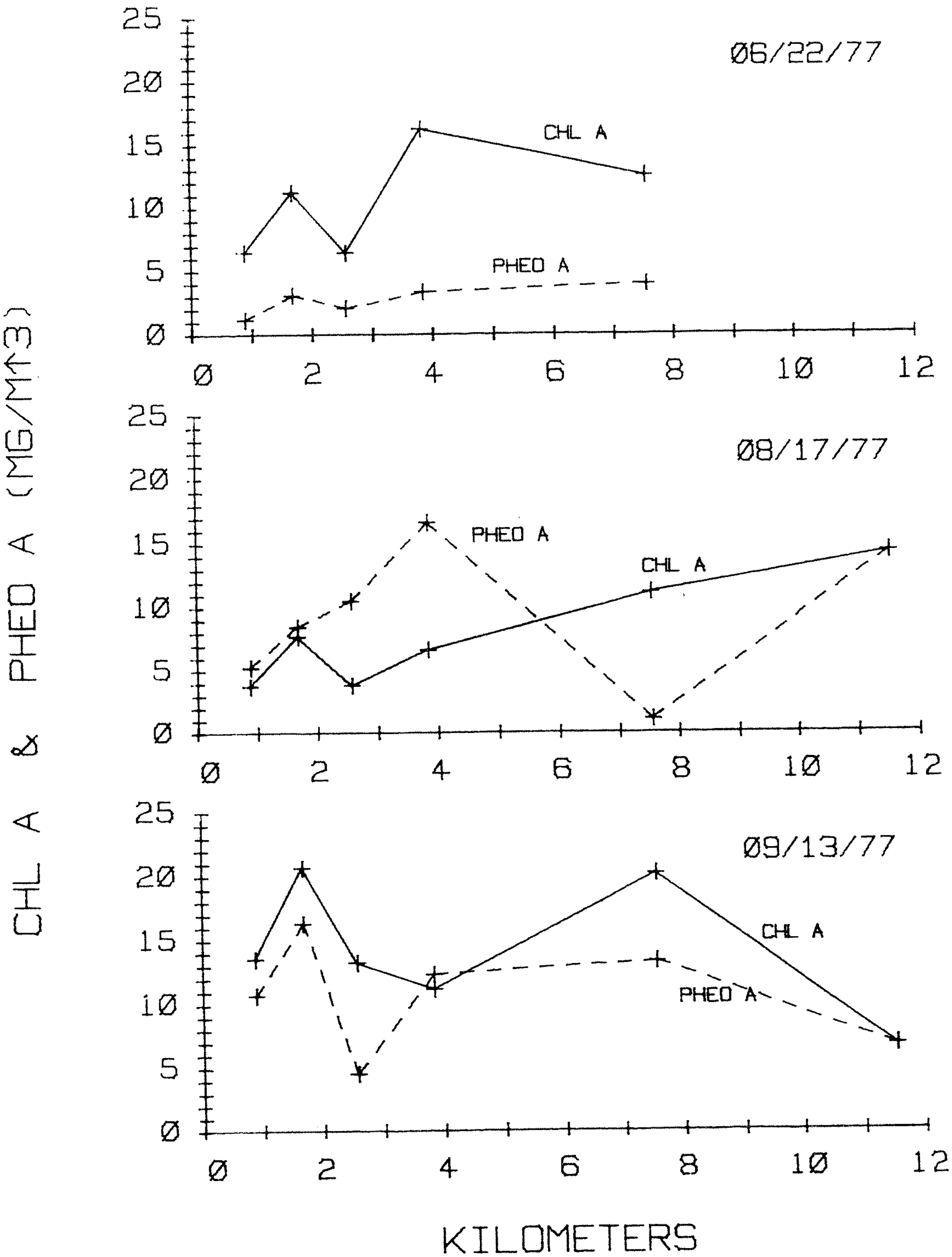

Figure 13. Chlorophyll a and pheophytin a concentrations (mg/m^3) in Budd Inlet for June, August, and September 1977.

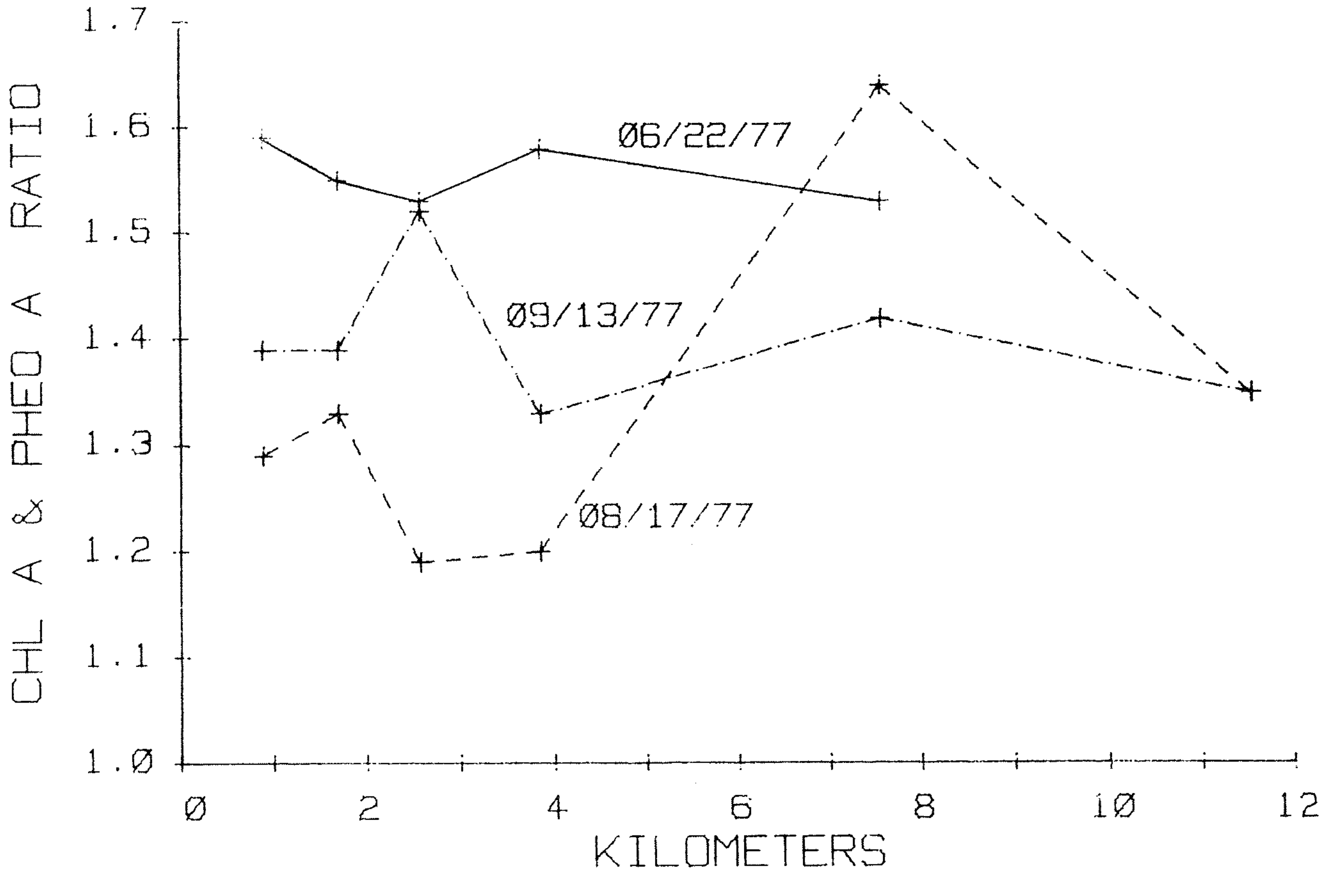

Figure 14. Ratio of chlorophyll a to pheophytin a during June, August, and September 1977 in Budd Inlet.

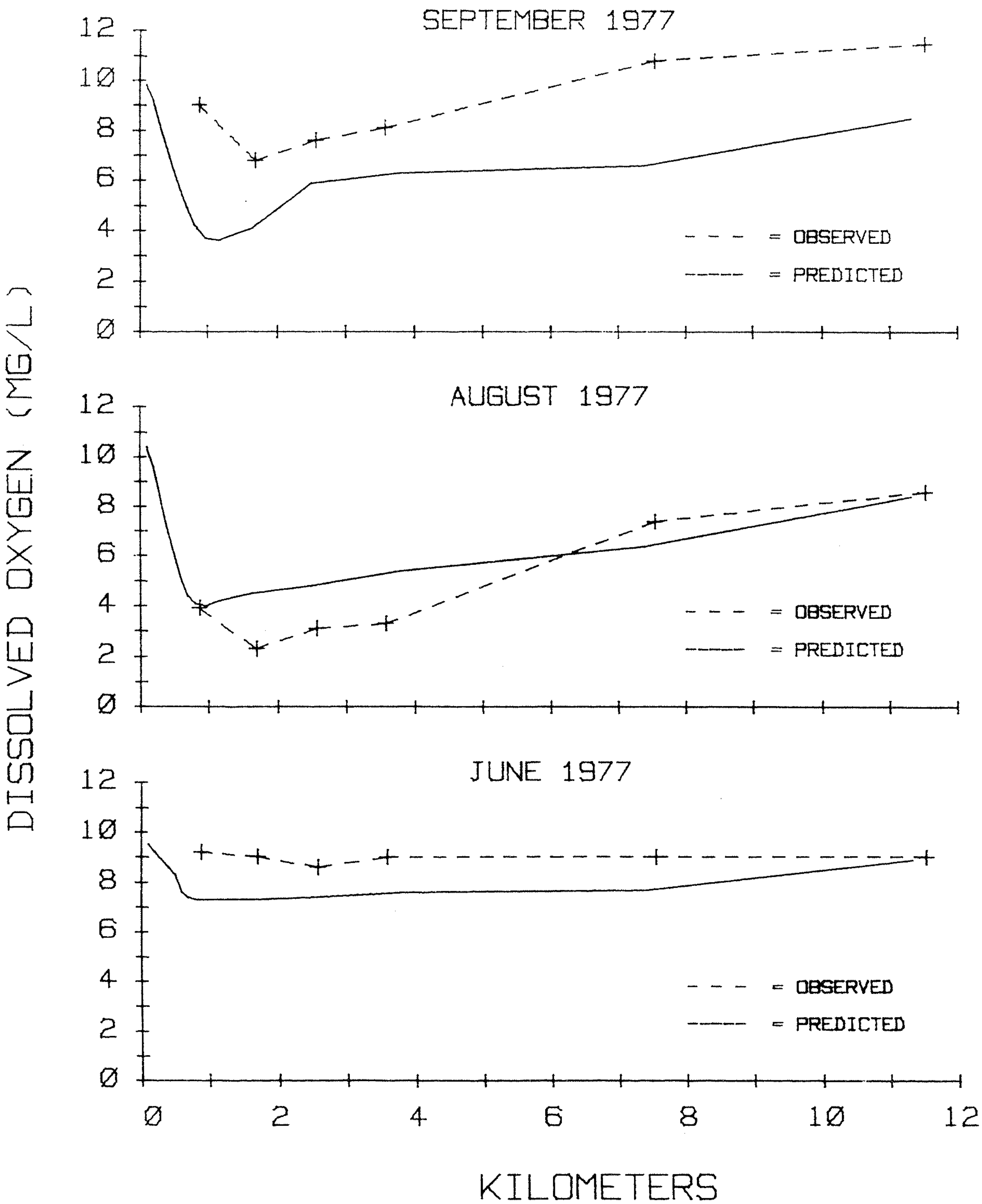

Figure 15. Model predicted and observed dissolved oxygen concentrations (mg/l) in Budd Inlet for June, August, and September 1977.

DO Sources

Three sources of dissolved oxygen were included in the model. These were: Capitol Lake discharge (primary contributor of DO from a point source); Puget Sound waters; and wind reaeration.

Wind reaeration appeared to play a significant role in the DO model. Winds in June and September were in the range of 10 to 20 mph and inlet DO concentrations were above 6 mg/l. Wind during the August sampling period was negligible and observed DO concentrations were extremely low (2.3 mg/l). By increasing wind velocity to 20 mph during the August simulation, more than 2 mg/l was added to the predicted DO concentrations in the inlet (Figure 16). The exact mechanism of wind on oxygen transfer at the air-water interface is not fully known. Wind-caused turbulence continuously circulates oxygen-saturated water with oxygen-depleted water just beneath the interface. The oxygen transfer coefficient evidently increases through wave generation, droplet formation, and wave breaking (Banks and Herrera, 1977).

DO Sinks

Phytoplankton decomposition and BOD loading from the Olympia STP were the two DO sinks addressed in the model.

The August 1977 DO sag in lower Budd Inlet corresponded directly with a large, decaying phytoplankton bloom. A direct relationship between chlorophyll *a*, BOD, and minimum DO concentrations has previously been established in the Duwamish River estuary (Welch, 1969). However, during this study pheophytin *a* appeared to be a better indicator of organic decomposition than chlorophyll *a*. Chlorophyll concentrations were calculated by two methods: (1) spectrophotometric method for chlorophyll *a* and (2) spectrophotometric method for pheophytin *a* (Table 6) (A.P.H.A., 1975). Generally, when the ratio is low, the difference between chlorophyll *a* and pheophytin *a* becomes smaller when it is computed by both methods. In fact, during August, pheophytin *a* concentrations (Method 2) approximated chlorophyll *a* concentrations (Method 1). Assuming the bloom during Welch's investigation was also in a similar state of decay, it would be possible to substitute pheophytin *a* for chlorophyll *a* in his equation as an estimation of oxygen uptake. Phytoplankton decomposition had a significant impact on predicted receiving water dissolved oxygen levels. The August simulation of three phytoplankton blooms with decreasing receiving water BOD concentrations resulted in higher DO concentrations throughout the inlet (Figure 17). A bloom half the intensity, therefore half the receiving water BOD, raised DO concentrations over 2 mg/l in the area of observed DO sags. This indicated that decaying phytoplankton blooms appear to have a substantial impact on DO concentrations in the inlet.

BOD loading from the treatment plant has been cited as a likely source of a localized DO sag (Stanley and Cloud, 1975; KCM, 1975). Model simulations during the critical month of August were made considering

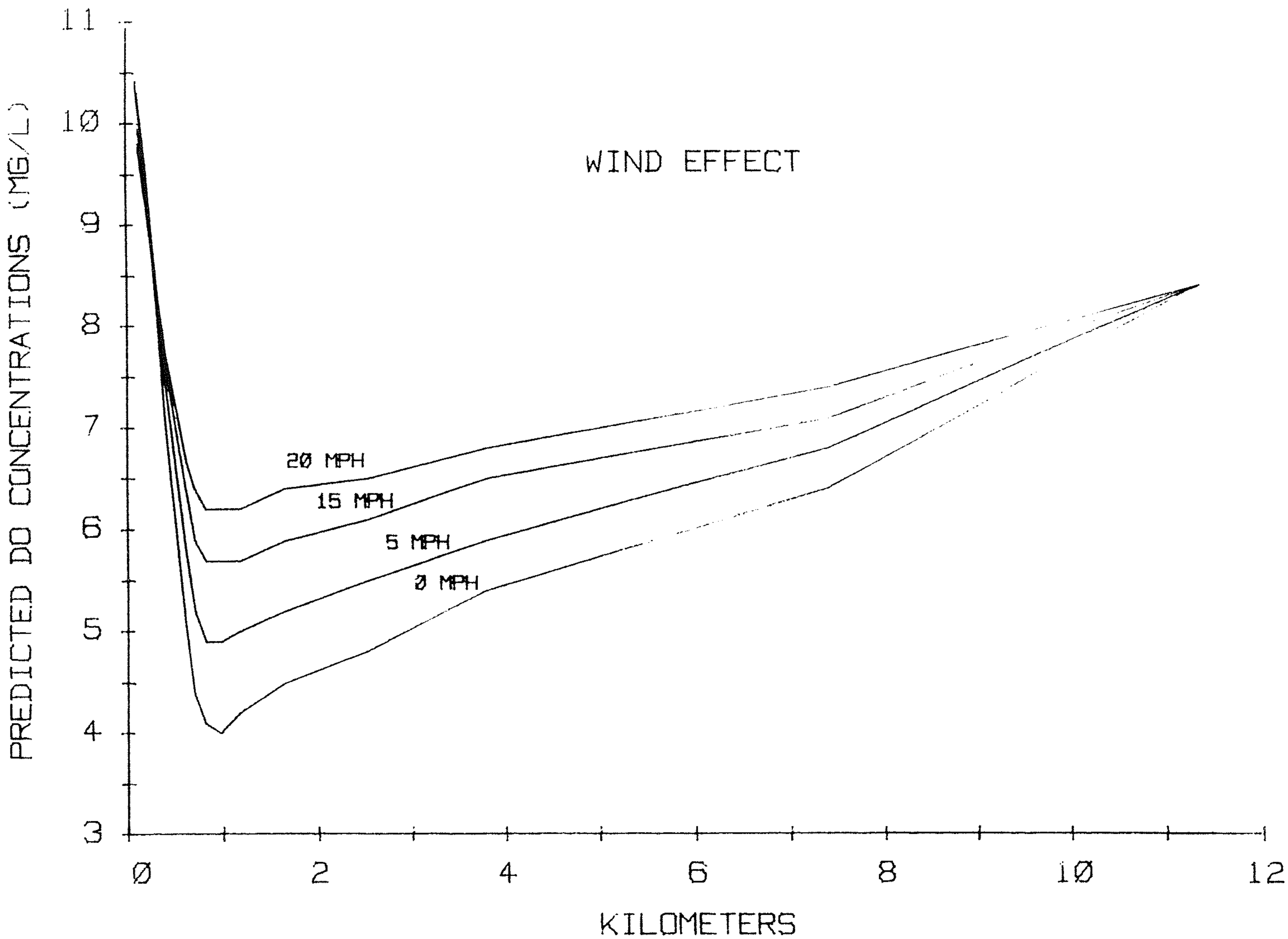

Figure 16. Model predicted DO concentrations (mg/l) in Budd Inlet during August 1977 with varying wind velocities.

Table 6. Chlorophyll data analyzed for chlorophyll *a* and pheophytin *a* in Budd Inlet during the summer of 1977.

		Method 1 Spectrophotometric Method for Chlorophyll *a*	Method 2 Spectrophotometric Method for Pheophytin *a*			
Date	Station	Chl *a* (mg/m^3)	Chl *a* (mg/m^3)	Pheo *a* (mg/m^3)	Chl *a* + Pheo *a* (mg/m^3)	Ratio
6/22/77	510	6.96	6.52	1.24	7.76	1.59
	522	12.78	11.27	3.12	14.39	1.55
	532	7.56	6.45	2.08	8.53	1.53
	542	17.91	16.31	3.33	19.64	1.58
	562	14.55	12.54	3.98	16.52	1.53
	592	---	---	---	---	---
8/17/77	510	6.70	3.80	5.29	9.09	1.29
	522	12.35	7.70	8.47	16.17	1.33
	532	9.48	3.85	10.52	14.37	1.19
	542	15.51	6.67	16.68	23.35	1.20
	562	11.61	11.23	1.12	12.35	1.64
	592	22.42	14.37	14.37	28.74	1.35
9/13/77	510	18.96	13.57	10.70	24.27	1.39
	522	29.39	20.69	16.36	37.05	1.39
	532	14.89	13.28	4.62	17.90	1.52
	542	17.59	11.23	12.35	23.58	1.33
	562	27.07	20.23	13.36	33.59	1.42
	592	10.24	6.81	6.76	13.57	1.35

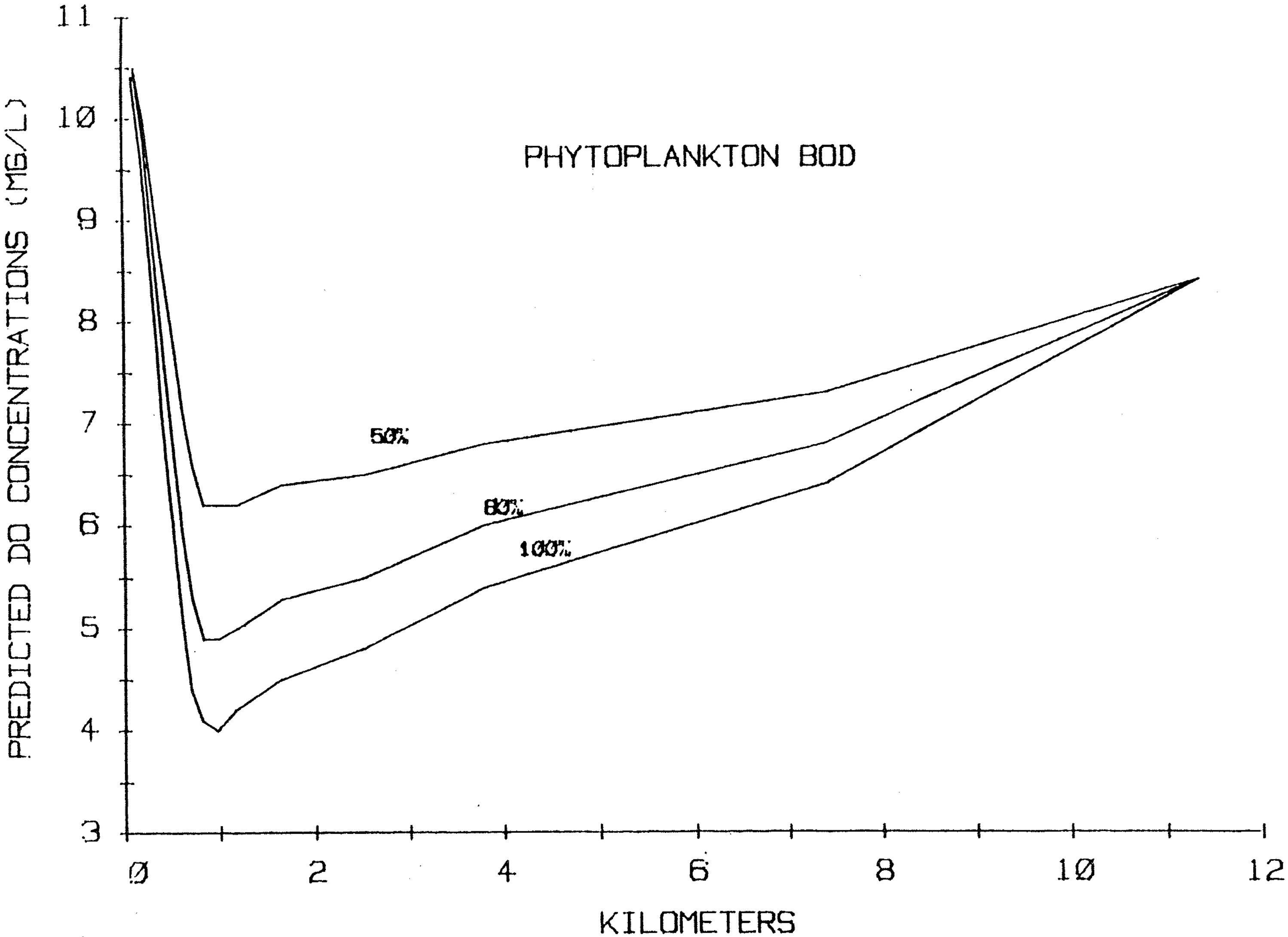

Figure 17. Model predicted DO concentrations (mg/l) in Budd Inlet during August 1977 with 100%, 80%, and 50% of the phytoplankton BOD.

the sewage treatment plant BOD loading, before and after its upgrade to secondary treatment. BOD loadings used in model computations were obtained from NPDES Permit No. WA-003706-1 (Table 7). It appears from model simulations that the BOD loading from the treatment plant has little effect on inlet DO concentrations. Only a 0.2-to-0.3 mg/l DO increase in the inner harbor might be expected after upgrading to secondary treatment (Figure 18). Another simulation was made using the same BOD loading rates but this time reducing the BOD of the bay water by 50 percent and similar results were obtained (Figure 19). Although DO concentrations are higher, it is obvious that the cause is from lower receiving water BOD.

CONCLUSIONS

1. Thirty-two percent of the basin volume (8.60×10^7 M^3) is involved in a mean tidal exchange. Assuming no mixing is occurring, this represents a mean flushing (replacement) time of 3.1 tidal cycles or approximately 1.5 days. Flushing "efficiency" for Budd Inlet was not determined. However, during the summer flushing efficiency may be reduced due to decreased freshwater inflow and northerly winds which tend to hold surface waters in Budd Inlet.

2. Capitol Lake, Moxlie Creek, the Olympia STP, and Ellis Creek contributed 99 percent of the total surface freshwater inflow into Budd Inlet (206 MGD).

3. The Olympia STP contributed 82 percent of the orthophosphate-phosphorus loading, with Capitol Lake contributing 80 percent of the nitrate-nitrogen loading to Budd Inlet from the monitored point sources. These sources, however, did not significantly increase receiving water nutrient concentrations. Puget Sound waters are naturally abundant in nutrients throughout the year. Therefore, it is evident that tertiary treatment (nutrient removal) is not necessary at the new Olympia treatment facility.

4. The Olympia STP contributed 81 percent of the BOD discharged to the inlet. All freshwater inputs considered, an average net loss of 26,200 pounds per day dissolved oxygen was attributed to BOD loading. However, the Olympia STP and other BOD sources did not appear to appreciably lower dissolved oxygen levels in Budd Inlet. Therefore, it appears moving the existing outfall into deepr waters would not significantly increase dissolved oxygen concentrations. Periodic dissolved oxygen sags coincided with other factors such as Capitol Lake flushing, indigeneous phytoplankton blooms, and optimal weather conditions.

Table 7. Monthly average effluent limitations before and after modification of the Olympia Sewage Treatment Plant to secondary levels.

Parameter	Before	After
Flow	15.3 mgd .67 m^3/sec	16.3 mgd .71 m^3/sec
BOD_5	704 mg/l 57,800 lb/day	30 mg/l 4,080 lb/day
Suspended Solids	210 mg/l 18,100 lb/day	30 mg/l 4,080 lb/day
Fecal Coliform Bacteria	700/100 ml	200/100 ml
pH	$6.0 \leq pH \leq 11.0$	$6.0 \leq pH \leq 9.0$

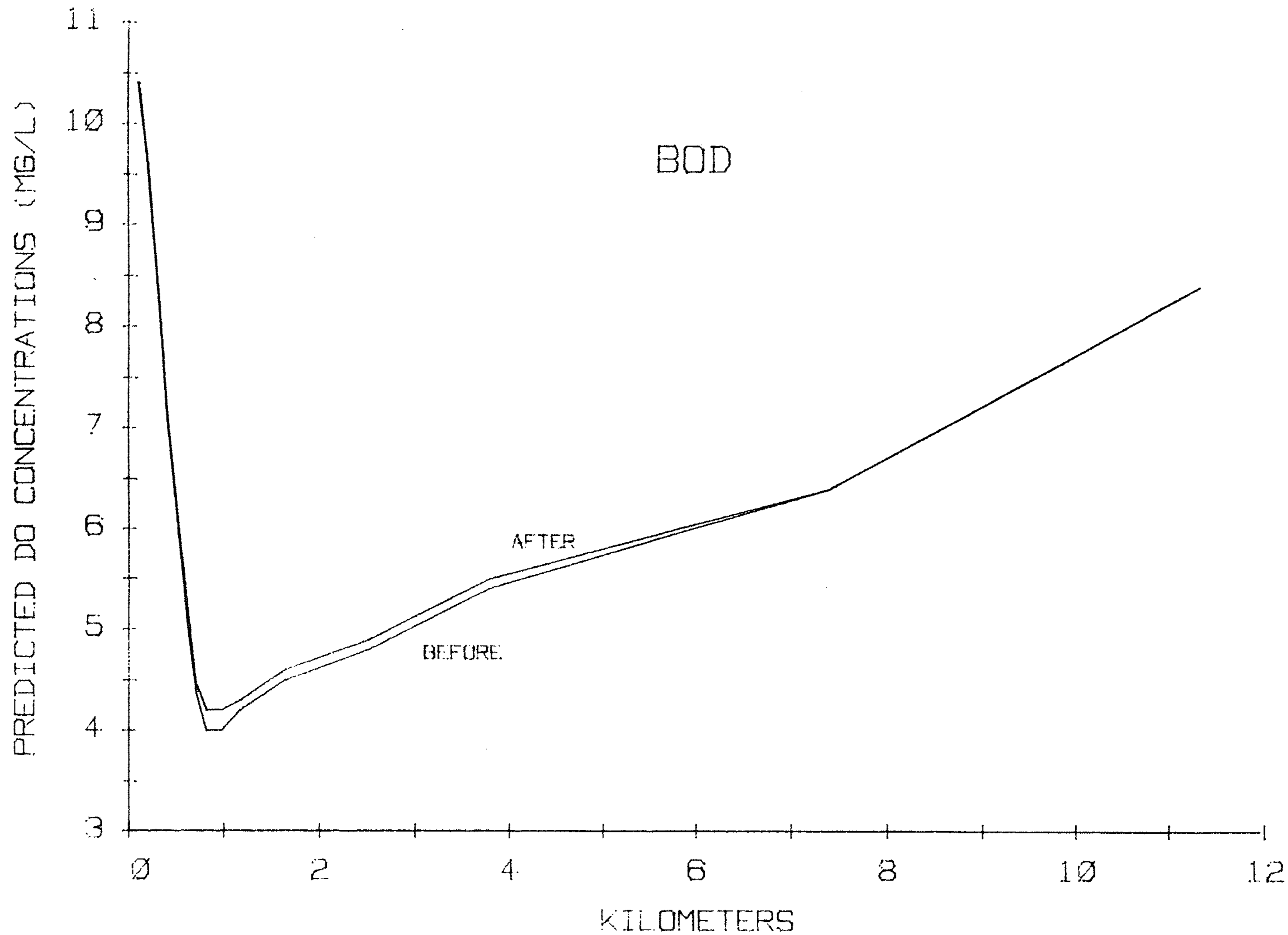

Figure 18. Predicted DO concentrations (mg/l) in Budd Inlet during August 1977 using BOD loading rates for the Olympia STP before and after upgrade to secondary treatment.

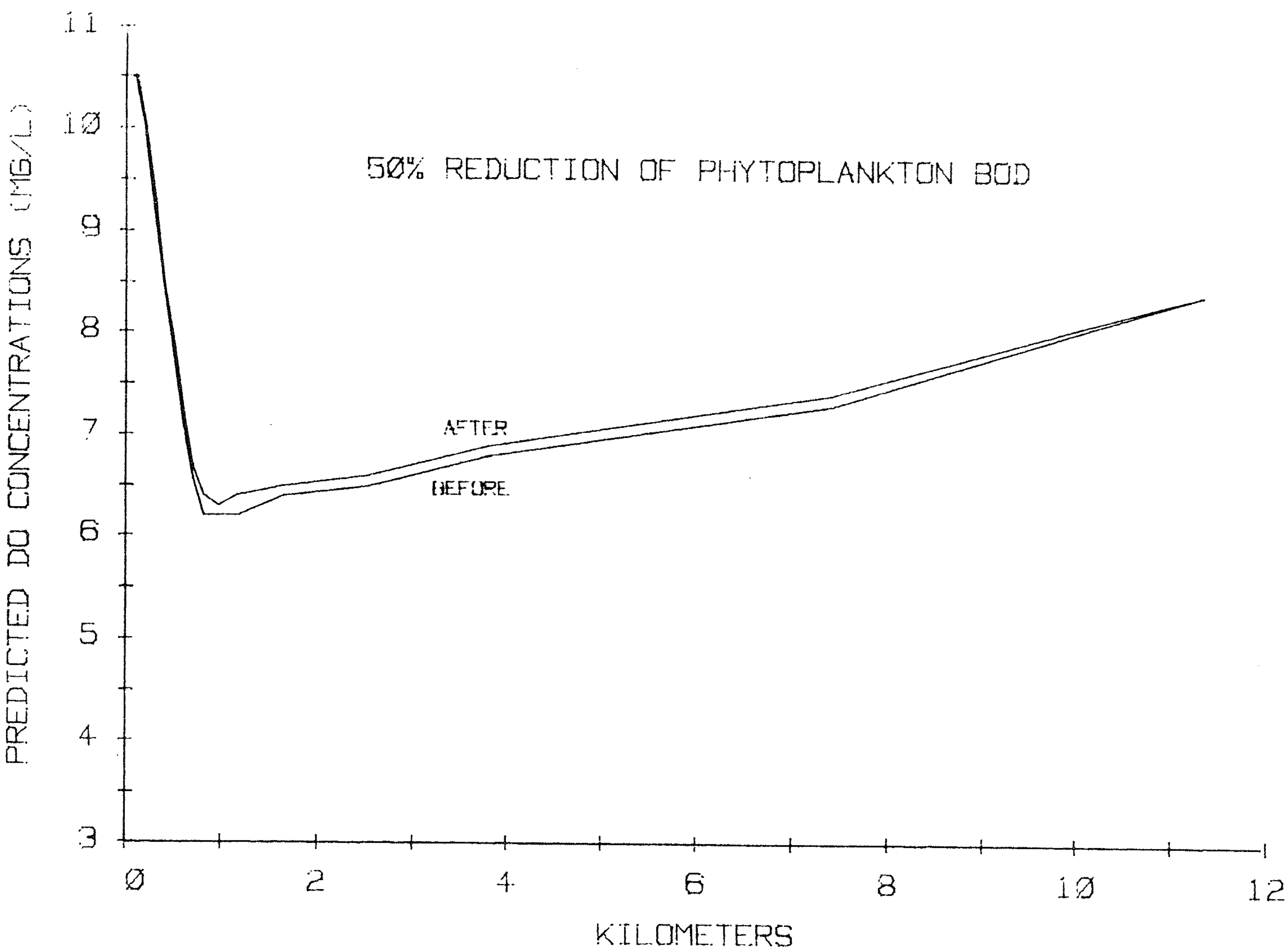

Figure 19. Predicted DO concentrations (mg/l) in Budd Inlet during August 1977 using BOD loading rates for the Olympia STP before and after upgrade to secondary treatment with 50% reduction in phytoplankton BOD.

5. Capitol Lake, Moxlie Creek, and the Olympia STP each contributed approximately one-third of the fecal coliform loading to Budd Inlet. By improving the disinfection process at the STP and eliminating all sanitary inputs to Moxlie Creek through sewer rehabilitation, there may be a 50 percent or greater reduction in fecal coliform loading to Budd Inlet. This may result in a class designation change from Class B to Class A marine waters for lower Budd Inlet.

6. The extensive DO sag in lower Budd Inlet during the summer of 1977 was primarily attributed to a decaying phytoplankton bloom. Phytoplankton blooms are a natural phenomenon in Puget Sound and Budd Inlet and will occur even after upgrade of the Olympia STP to secondary treatment.

7. Model predictions for dissolved oxygen were mainly influenced by decaying phytoplankton blooms (DO sink) and wind reaeration (DO source). The model also showed that upgrading the Olympia STP to secondary treatment, resulting in a substantial reduction in biochemical oxygen demand, would not significantly increase dissolved oxygen concentrations in the receiving water.

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APPENDIX I

STATION LOCATIONS AND DESCRIPTIONS

DEPARTMENT OF ECOLOGY

Office of Water Programs
Water Quality Management Division
Water & Wastewater Monitoring Section

BUDD510 BUDD INLET AT YACHT BASIN-BUDD001

STORET Minor Basin: Puget Sound   STORET Sub Basin: Deschutes

Latitude: 47 02 52.0   Elevation (Feet): 0   Water Class: B
Longitude: 122 54 20.0   County: Thurston   Segment: 06-13-03

Agency: 21540000   State: Washington   Sta Type: Marine

Located off center of most seaward pier running east/west at the Olympia Yacht Basin - this is the same location as BUDD001 in the marine air flight network.

BUD521 BUDD INLET OUT SHIP TURN BASIN

STORET Minor Basin: Puget Sound   STORET Sub Basin: Deschutes

Latitude: 47 03 23.0   Elevation (Feet): 0   Water Class: B
Longitude: 122 54 32.0   County: Thurston   Segment: 06-13-03

Agency: 21540000   State: Washington   Sta Type: Marine

Located on a line from the large, green, sheet metal warehouse through center of crane area on port docks - outside of ship turning basin.

BUD522 BUDD INLET IN SHIP TURN BASIN

STORET Minor Basin: Puget Sound   STORET Sub Basin: Deschutes

Latitude: 47 03 24.0   Elevation (Feet): 0   Water Class: B
Longitude: 122 54 21.0   County: Thurston   Segment: 06-13-03

Agency: 21540000   State: Washington   Sta Type: Marine

Located along the same line as BUD521 - inside the ship turning basin.

BUD523 BUDD INLET NEAR CASCADE POLE

STORET Minor Basin: Puget Sound   STORET Sub Basin: Deschutes

Latitude: 47 03 26.0   Elevation (Feet): 0   Water Class: B
Longitude: 122 53 48.0   County: Thurston   Segment: 06-13-03

Agency: 21540000   State: Washington   Sta Type: Marine

Located along the same line as BUD521 - approximately 240 meters due east of center of southern dock at Cascade Pole.

BUD531 BUDD INLET WSW SOUTH CHAN MARKER

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 03 43.0	Elevation (Feet):	0	Water Class:	B
Longitude:	122 54 31.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Marine

Located on a line from the plywood plant through the southernmost channel marker, approximately 370 meters WSW of that channel marker.

BUD532 BUDD INLET AT SOUTH CHAN MARKER

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 03 45.0	Elevation (Feet):	0	Water Class:	B
Longitude:	122 54 13.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Marine

Located along the same line as BUD531 - at the southernmost channel marker.

BUD533 BUDD INLET ENE SOUTH CHAN MARKER

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 03 47.0	Elevation (Feet):	0	Water Class:	B
Longitude:	122 53 57.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Marine

Located along the same line as BUD531 - approximately 370 meters ENE of southernmost channel marker.

BUD541 BUDD INLET W NORTH CHAN MARKER

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 04 13.0	Elevation (Feet):	0	Water Class:	A
Longitude:	122 54 49.0	County:	Thurston	Segment:	25-02-00
Agency:	21540000	State:	Washington	Sta Type:	Marine

Located on a line from the northernmost marker to entrance channel of ship turning basin to yellow house visible on west shore - approximately 400 meters west of that channel marker.

BUD542 BUDD INLET AT NORTH CHAN MARKER

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 04 12.0	Elevation (Feet):	0	Water Class:	A
Longitude:	122 54 28.0	County:	Thurston	Segment:	25-02-00
Agency:	21540000	State:	Washington	Sta Type:	Marine

Located along the same line as BUD541 - at the northernmost channel marker of the ship turning basin.

BUD543 BUDD INLET E NORTH CHAN MARKER

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 04 10.0
Longitude: 122 54 10.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located along the same line as BUD541 - approximately 490 meters east of that channel marker.

BUD551 BUDD INLET AT SHIP CHAN ENTRANCE

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 05 10.0
Longitude: 122 55 27.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located at the flashing (4 sec) marker at the entrance to the dredged ship channel.

BUD552 BUDD INLET EAST OF GILES LANDING

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 05 12.0
Longitude: 122 54 48.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located on a line from the marker of BUD551 to Giles' Landing, visible on the east shore - approximately 800 meters east of that marker.

BUD553 BUDD INLET WEST OF GILES LANDING

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 05 14.0
Longitude: 122 54 15.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located along the same line as BUD552 - approximately 360 meters west of Giles' Landing.

BUD561 BUDD INLET IN TYKLE COVE

STORET Minor Basin: puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 06 01.0
Longitude: 122 54 15.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located at the westernmost piling in Tykle Cove.

BUD562 BUDD INLET NEAR GSA DOCKS

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 05 59.0
Longitude: 122 54 42.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located on a line from BUD561 to GSA docks visible on the east shore - approximately 1.3 km east of designated piling.

BUD563 BUDD INLET WEST OF GSA DOCKS

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 05 57.0
Longitude: 122 53 57.0
Elevation (Feet): 0
County: Thurston
Water Class: 0
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located along the same line as BUD562 - approximately 900 meters west of GSA docks.

BUD571 BUDD INLET NEAR GULL HARBOR

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 07 10.0
Longitude: 122 55 02.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located on a line from Beverly Beach dock west shore (approximately 1.3 km north of Tykle Cove) to white house visible at close range on east shore (approximately 700 meters north of Gull Harbor) - 400 meters from west shore.

BUD572 BUDD INLET NR GULL HBR MIDCHAN

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 07 11.0
Longitude: 122 54 31.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located along the same line as BUD571 - approximately 1.0 km from either shore.

BUD573 BUDD INLET NR GULL HBR E SHORE

STORET Minor Basin: Puget Sound
STORET Sub Basin: Deschutes

Latitude: 47 07 12.0
Longitude: 122 54 10.0
Elevation (Feet): 0
County: Thurston
Water Class: A
Segment: 25-02-00

Agency: 21540000
State: Washington
Sta Type: Marine

Located along the same line as BUD571 - approximately 640 meters from the east shore.

BUD581 BUDD INLET NR LANDMARK DRIVEWAY

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude: 47 08 03.0 Elevation (Feet): 0 Water Class: A
Longitude: 122 55 17.0 County: Thurston Segment: 25-02-00

Agency: 21540000 State: Washington Sta Type: Marine

Located on a line from landmark driveway visible at close range on west shore (approximately 2.8 km north of Tykle Cove) to east shore (approximately 600 meters south of Wofflemeyer Point) - approximately 400 meters off west shore.

BUD582 BUDD INLET OFF WEST SHORE

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude: 47 08 05.0 Elevation (Feet): 0 Water Class: A
Longitude: 122 54 57.0 County: Thurston Segment: 25-02-00

Agency: 21540000 State: Washington Sta Type: Marine

Located along the same line as BUD581 - approximately 900 meters off west shore.

BUD583 BUDD INLET OFF EAST SHORE

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude: 47 08 08.0 Elevation (Feet): 0 Water Class: A
Longitude: 122 54 29.0 County: Thurston Segment: 25-02-00

Agency: 21540000 State: Washington Sta Type: Marine

Located along the same line as BUD581 - approximately 300 meters off east shore.

BUD591 BUDD INLET NEAR COOPER POINT

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude: 47 08 43.0 Elevation (Feet): 0 Water Class: A
Longitude: 122 55 10.0 County: Thurston Segment: 25-02-00

Agency: 21540000 State: Washington Sta Type: Marine

Located on a line from the northernmost house on Cooper's Point to the pink house visible on the east shore (i.e., Jeal Point) - approximately 460 meters east of Cooper Point.

BUD592 BUDD INLET NEAR JEAL POINT

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude: 47 08 41.0 Elevation (Feet): 0 Water Class: A
Longitude: 122 54 29.0 County: Thurston Segment: 25-02-00

Agency: 21540000 State: Washington Sta Type: Marine

Located along the same line as BUD591 - approximately 640 meters west of Jeal Point.

BUD601 JOY AVE. & EAST BAY DRIVE

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 03 32.0	Elevation (Feet): 0	Water Class:
Longitude: 122 53 37.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Pump station at the intersection of Joy Avenue and East Bay Drive (8-inch emergency bypass, only for pump failure). Effluent enters into East Bay of Budd Inlet.

BUD602 SAN FRANCISCO & EAST BAY DRIVE

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 03 26.0	Elevation (Feet): 0	Water Class:
Longitude: 122 53 35.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

24-inch storm overflow pipe. Access in grassy bank just north of intersection of San Fransciso Street and East Bay Drive. Manhole is farthest north and closest to sidewalk. Outfall located across East Bay Drive and down private driveway, behind private dock. Effluent enters into East Bay of Budd Inlet.

BUD603 GLASS ST. & EAST BAY DRIVE

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 59.0	Elevation (Feet): 0	Water Class:
Longitude: 122 53 31.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Access to storm overflow at intersection of Glass Street and East Bay Drive. In northbound traffic lane on East Bay Drive. (Outfall is buried.) Overflow enters into East Bay of Budd Inlet.

BUD604 THURSTON AVE. & EAST BAY DRIVE

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 54.0	Elevation (Feet): 0	Water Class:
Longitude: 122 53 33.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Access to 18-inch storm overflow is at the intersection of Thurston Avenue and East Bay Drive (Thurston Avenue is not a through street). Access is in northbound traffic lane on East Bay Drive. Of the two manholes in the area, it is the one farthest south. Overflow enters into East Bay of Budd Inlet. Overflow pipe is 12-inch diameter.

BUD605 STATE AVE. & CHESTNUT AVE.

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 48.0 Longitude: 122 53 36.0	Elevation (Feet): 0 County: Thurston	Water Class: Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Access to 72-inch combined storm sewer overflow is at the intersection of State Avenue and Chestnut Street. Manhole is located in dirt and gravel sidewalk on north side of State Avenue. Outfall is located just on other side of fence from access and empties into the southernmost end of East Bay in Budd Inlet. Outfall pipe narrows to 30 inches in diameter at end.

BUD606 OLYMPIA STP EMERGENCY BYPASS

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 03 00.0 Longitude: 122 53 47.0	Elevation (Feet): 0 County: Thurston	Water Class: Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

42-inch emergency bypass for the Olympia Sewage Treatment Plant, running due east from treatment plant.

BUD607 OLYMPIA STP OUTFALL

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 03 33.0 Longitude: 122 54 19.0	Elevation (Feet): 0 County: Thurston	Water Class: Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Main outfall for the Olympia Sewage Treatment Plant, at north end of Washington Street near Stefans on Budd Inlet Restaurant. Outfall pipe is a 30-inch diffusser pipe.

BUD608 OLYMPIA STP BYPASS

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 57.0 Longitude: 122 54 11.0	Elevation (Feet): 0 County: Thurston	Water Class: Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

48-inch overflow for the Olympia Sewage Treatment Plant, located jsut off end of "C" Street. Effluent enters into West Bay of Budd Inlet.

BUD609 STATE AVE. & WATER ST.

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 45.0 Longitude: 122 54 13.0	Elevation (Feet): 0 County: Thurston	Water Class: Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

Pump station located just north of the intersection of State Avenue and Water Street. The effluent is a combined pumped overflow with a 30-inch outfall pipe. Effluent enters into West Bay of Budd Inlet.

BUD610 BRENNER ST. & 4th AVE.

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 02 41.0	Elevation (Feet):	0	Water Class:	
Longitude:	122 54 27.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State;	Washington	Sta Type:	Disch.

An 8-inch storm overflow with access near Brenner Street and 4th Avenue pump station. Now abandoned.

BUD611 OLYMPIA WAY & 4th AVE.

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 02 40.0	Elevation (Feet):	0	Water Class:	
Longitude:	122 54 39.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Disch.

Access to combined overflow in left-hand uphill turn lane at intersection of Olympia Way and 4th Avenue in crosswalk. Southwesternmost of the two.

BUD612 JACKSON AVE. & WEST BAY DRIVE

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 02 55.0	Elevation (Feet):	0	Water Class:	
Longitude:	122 54 43.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Disch.

Access to 6-inch storm overflow at projected intersection of Jackson Avenue and West Bay Drive in middle of road. Access is farthest north of two manholes in area. Overflow enters into West Bay of Budd Inlet.

BUD613 FOOTE AVE. & JACKSON AVE.

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 02 59.0	Elevation (Feet):	0	Water Class:	
Longitude:	122 54 44.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Disch.

Access to 15-inch sanitary overflow at north end of Foote Street from intersection of Jackson Avenue and Foote Street. Access 5 to 10 feet over east bank marked with pipe stakes along private drive. Access buried under leaves. Overflow enters into West Bay of Budd Inlet.

BUD614 BRAWNE AVE. & WEST BAY DRIVE

STORET Minor Basin: Puget Sound STORET Sub Basin: Deschutes

Latitude:	47 03 10.0	Elevation (Feet):	0	Water Class:	
Longitude:	122 54 44.0	County:	Thurston	Segment:	06-13-03
Agency:	21540000	State:	Washington	Sta Type:	Disch.

Access for 15-inch combined overflow at intersection of Brawne Ave. and West Bay Drive, in south bound lane. Access is the center manhole of three located in area. Overflow enters into West Bay of Budd Inlet.

BUD615 WEST BAY MARINA PUMP STATION

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 03 47.0	Elevation (Feet): 0	Water Class:
Longitude: 122 54 54.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Disch.

15-inch storm overflow near pump station, just south of West Bay Marina. Access in northbound traffic lane near railroad tracks.

BUD616 PERCIVAL CREEK GAUGING STATION

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 01 56.0	Elevation (Feet): 0	Water Class: A
Longitude: 122 55 08.0	County: Thurston	Segment: 06-13-100
Agency: 21540000	State: Washington	Sta Type: Stream

Percival Creek gauging station. Approximately 0.4 miles upstreamfrom Deschutes Parkway, at upstream side of footbridge across creek. Flow enters into Capitol Lake.

BUD617 DESCHUTES RIVER GAUGING STATION

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 00 42.0	Elevation (Feet): 0	Water Class: A
Longitude: 122 54 07.0	County: Thurston	Segment: 06-13-04
Agency: 21540000	State: Washington	Sta Type: Stream

Deschutes gauging station. In middle of Tumwater Valley bridge near intersection of Capitol Blvd. and E Street. Flow enters into Capitol Lake.

BUD618 ELLIS CREEK GAUGING STATION

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 04 27.0	Elevation (Feet): 0	Water Class: A
Longitude: 122 53 38.0	County: Thurston	Segment: 06-13-03
Agency: 21540000	State: Washington	Sta Type: Stream

Ellis Creek gauging station. Station located at upstream end of culvert under East Bay Drive. Flow enters into Budd Inlet.

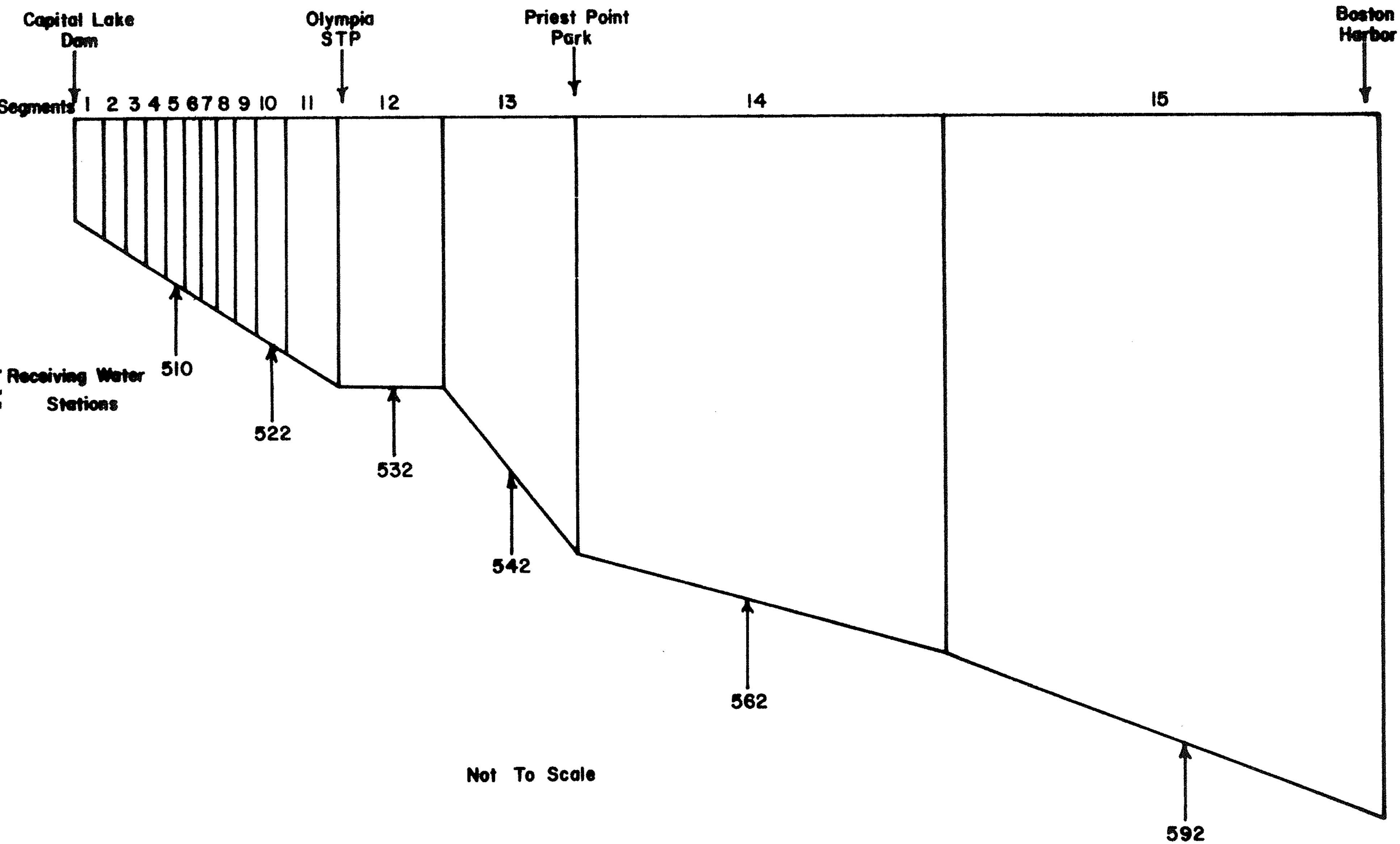
BUD619 CAPITOL LAKE GAUGE/POINT SOURCE

STORET Minor Basin: Puget Sound	STORET Sub Basin: Deschutes	
Latitude: 47 02 37.0	Elevation (Feet): 0	Water Class: LC
Longitude: 122 54 28.0	County: Thurston	Segment: 06-13-100
Agency: 21540000	State: Washington	Sta Type: Lake

Capitol Lake. Sampling station located at east tidal gate near fish ladder on south side of dam. Discharge from Capitol Lake enters into the southernmost end of West Bay of Budd Inlet.

APPENDIX II

MODEL INPUT AND PROGRAM LISTING


Capital Lake Dam
Olympia STP
Priest Point Park
Boston Harbor
Segments 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Receiving Water Stations
510
522
532
542
562
592
Not To Scale

MODEL MORPHOLOGICAL DATA

Seg	Du	Dd	xD	Wu	Wd	xW	CAu	L	Vol
1	2.0	3.0	2.50	59	90	74.5	118	100	1.86×10^{4}
2	3.0	2.3	2.65	90	121	105.5	270	100	2.80×10^{4}
3	2.3	4.6	3.45	121	152	136.5	278	100	4.71×10^{4}
4	4.6	3.7	4.15	152	183	167.5	699	100	6.95×10^{4}
5	3.7	3.0	3.35	183	215	199.0	677	100	6.67×10^{4}
6	3.0	4.3	3.65	215	246	230.5	645	100	8.41×10^{4}
7	4.3	4.8	4.55	246	277	261.5	1058	100	1.19×10^{5}
8	4.8	6.1	5.45	277	330	303.5	1330	123	2.03×10^{5}
9	6.1	7.6	6.85	330	384	357.0	2013	150	3.67×10^{5}
10	7.6	6.7	7.15	384	366	375.0	2918	200	5.36×10^{5}
11	6.7	4.6	5.65	366	549	457.5	2452	473	1.22×10^{6}
12	4.6	4.3	4.45	549	1325	937.0	2525	869	3.62×10^{6}
13	4.3	6.7	5.50	1325	1641	1483.0	5698	1280	1.04×10^{7}
14	6.7	9.1	7.90	1641	2210	1925.5	10995	3612	5.49×10^{7}
15	9.1	18.5	13.80	2210	2142	2176.0	20111	3932	1.18×10^{8}
							39627		

Seg = Segment
Du = Depth upstream segment
Dd = Depth downstream segment
xD = Mean depth of segment
Wu = Width upstream segment
Wd = Width downstream segment
xW = Mean width of segment
CAu = Cross-sectional area of upstream segment
L = Length of segment
Vol = Volume of segment

22 JUNE 1977

SEGMENT	PREDICTED SEGMENT AVERAGED D.O.
1	9.5 mg/l
2	9.2 mg/l
3	8.9 mg/l
4	8.6 mg/l
5	8.3 mg/l
6	7.6 mg/l
7	7.4 mg/l
8	7.3 mg/l
9	7.3 mg/l
10	7.3 mg/l
11	7.3 mg/l
12	7.4 mg/l
13	7.6 mg/l
14	7.7 mg/l
15	8.9 mg/l

22 JUNE 1977

MODEL INPUT

SEGMENT	Salinity	Temperature	Diffusion Coefficient	ROD Data
1	0.7	19.5	2.4	1.1
2	2.5	19.3	1.8	1.1
3	5.3	18.4	2.8	1.1
4	9.0	18.2	1.5	1.1
5	13.0	17.3	2.3	1.1
6	22.2	16.2	1.7	1.1
7	26.5	15.4	3.0	1.1
8	26.7	13.4	68.5	1.1
9	27.0	13.2	37.1	1.8
10	27.5	12.9	20.8	1.8
11	28.0	12.8	59.6	1.8
12	29.0	12.7	54.6	1.5
13	29.8	12.6	46.0	1.8
14	30.0	12.4	273.6	2.0
15	30.2	12.3	163.9	2.0
			167.2	

DEOXYGENATION RATE = .1

DATA

	TRIBUTARY	PUGET SOUND	POINT SOURCE
SEGMENT			12
FLOW (M↑3/SEC)	5.57		0.35
DO (MG/L)	9.9	9.0	0.2
BOD (MG/L)	2.0	2.0	600.0

WIND SPEED

mph = 20

kmph = 32.2

17 AUGUST 1977

SEGMENT	PREDICTED SEGMENT AVERAGED D.O.
1	10.4 mg/l
2	9.6 mg/l
3	8.3 mg/l
4	7.1 mg/l
5	6.1 mg/l
6	5.1 mg/l
7	4.4 mg/l
8	4.1 mg/l
9	4.0 mg/l
10	4.2 mg/l
11	4.5 mg/l
12	4.8 mg/l
13	5.4 mg/l
14	6.4 mg/l
15	8.4 mg/l

17 AUGUST 1977

MODEL INPUT

SEGMENT	Salinity	Temperature	Diffusion Coefficient	ROD Data
1	0.6	23.0	1.2	2.2
2	2.4	22.9	0.8	2.2
3	5.2	22.6	1.3	2.2
4	8.7	22.1	0.8	2.2
5	12.7	20.8	1.1	2.2
6	17.1	20.0	1.4	2.2
7	21.5	19.2	1.1	2.2
8	25.0	18.4	1.7	2.2
9	26.0	18.0	5.2	2.8
10	27.0	17.4	4.9	2.8
11	27.7	16.8	20.5	2.8
12	28.0	16.4	86.9	3.1
13	28.2	16.2	85.8	3.8
14	28.3	15.8	252.4	1.1
15	28.4	15.3	150.8	3.5
			76.8	

DEOXYGENATION RATE = .1

DATA

	TRIBUTARY	PUGET SOUND	POINT SOURCE
SEGMENT			12
FLOW (M↑3/SEC)	2.72		0.42
DO (MG/L)	10.8	8.9	0.1
BOD (MG/L)	2.0	3.5	653.0

WIND SPEED

mph = 0

kmph = 0

13 SEPTEMBER 1977

SEGMENT	PREDICTED SEGMENT AVERAGED D.O.
1	9.8 mg/l
2	9.2 mg/l
3	8.2 mg/l
4	7.3 mg/l
5	6.4 mg/l
6	5.6 mg/l
7	4.9 mg/l
8	4.2 mg/l
9	3.7 mg/l
10	3.6 mg/l
11	4.1 mg/l
12	5.9 mg/l
13	6.3 mg/l
14	6.6 mg/l
15	8.5 mg/l

13 SEPTEMBER 1977

MODEL INPUT

SEGMENT	Salinity	Temperature	Diffusion Coefficient	ROD Data
1	0.3	17.7	1.9	3.1
2	1.2	17.6	1.4	3.1
3	2.6	17.5	2.2	3.1
4	4.4	17.4	1.3	3.1
5	6.6	17.3	1.7	3.1
6	8.9	17.1	2.4	3.1
7	11.4	17.0	1.8	3.1
8	14.0	16.9	2.1	3.1
9	16.7	16.8	1.9	3.7
10	19.2	16.5	2.3	3.7
11	23.6	16.4	4.3	3.7
12	27.6	16.2	10.1	2.1
13	28.0	15.8	71.5	3.3
14	28.1	15.3	422.0	3.4
15	28.2	14.8	252.1	2.5
			128.4	

DEOXYGENATION RATE = .1

DATA

	TRIBUTARY	PUGET SOUND	POINT SOURCE
SEGMENT			12
FLOW (M↑3/SEC)	4.58		0.46
DO (MG/L)	10.2	11.5	0.6
BOD (MG/L)	2.0	2.5	607.0

WIND SPEED

mph = 10

kmph = 16.1

PROGRAM LISTING

```
   1 REM %PROGRAM NAME   "MODEL"
 100 COM A(3,16),Y(15),CO(15),C(2,16),Q(15),H(15),H1(15),SO(15
      ),EO(16),D$30
 110 COM T(15),K(2),VO(15),V(15),W(15),Z(15),AO(16),XO(16),S(1
      5)
 120 COM Q,Q1,Q4,C4,L4,C1(2),C2(2),C4(2,15),MO
 130 DIM E$40,E1$80
 140 INIT(2A)E$
      :INIT(8B)E1$
 150 SELECT #1B10,#2B10,#3B10
 160 A1$="ST"
      :B1$="DC"
      :C1$="RO"
 170 PRINT HEX(03)
      :INPUT "DATE",D$
      :PRINT HEX(0A0A)
 180 INPUT "SAMPLING MONTH (MM) ",MO
      :PRINT HEX(0A0A0A)
 190 PRINT "DEOXYGENATION RATE ( DAYS↑-1 ) =  0.10"
      :K1=.10
      :PRINT HEX(0A)
 200 CONVERT MO  TO MO$,(##)
      :A$,B$,C$=ALL(00)
 210 REM WEATHER DATA
      :INPUT "WIND SPEED ( mph ) ",W2
      :REM CONVERT TO kmph
      :W1=W2*1.609344
 220 REM %*** MORPHOLOGICAL DATA INPUTS ***
 230 REM *** READ 'NUMBER OF SEGMENTS', NO
      :READ NO
 240 REM *** MAT READ 'U/S SEGMENT DEPTH (m)', H(
      :MAT READ H
 250 REM *** MAT READ ' CROSS-SECTIONAL AREA (m↑2) ', AO(
      :MAT READ AO
 260 REM *** MAT READ ' SEGMENT LENGTH (m) ', XO(
      :MAT READ XO
 270 REM *** MAT READ 'U/S SEGMENT WIDTH (m) ', W(
      :MAT READ W
 280 REM *** MAT READ 'SEGMENT VOLUME (m↑3) ', V(
      :MAT READ VO
 290 REM *** MAT READ MEAN SEGMENT DEPTH (m)   , H1(
      :MAT READ H1
 300 REM %**********************************
 310 I9=0
 320 PRINTUSING  TO A$,"##";MO$;A1$
      :A$=STR(A$,3,4)
      :DATA LOAD DC OPEN T #1,A$
 330 PRINTUSING  TO B$,"##";MO$;B1$
      :B$=STR(B$,3,4)
      :DATA LOAD DC OPEN T #2,B$
 340 PRINTUSING  TO C$,"##";MO$;C1$
      :C$=STR(C$,3,4)
```

```
      :DATA LOAD DC OPEN T #3,C$
 350 IF I9>0  THEN  360
 360 I9=1
 370 PRINT HEX(030A0A0A0A)
 380 INPUT "NEW SEGMENT TEMPERATURE AND SALINITY (1=YES, O=NO)
      ",K9
      :PRINT HEX(030A)
 390 IF K9=0  THEN  450
 400 PRINT TAB(3);"SEGMENT";TAB(15);"SEGMENT AVERAGED";TAB(55)
      ;"SATURATED DO";HEX(0D0A)
 410 GOSUB 1830
 420 FOR I=1  TO NO
      :PRINT TAB(5);I;TAB(15);
      :INPUT "SALINITY (o/OO)",S(I)
      :PRINT TAB(22);
      :INPUT "TEMP (C)",T(I)
      :GOSUB 1740
      :PRINT TAB(56);HEX(0C);CO(I)
      :PRINT HEX(0A)
      :NEXT I
 430 DATA SAVE DC #1,S(),T(),CO()
 440 GOTO  460
 450 DATA LOAD DC #1,S(),T(),CO()
 460 FOR J=1  TO NO
      :Q(J)=0
      :NEXT J
 470 PRINT HEX(030A0A0A0A)
 480 INPUT "NEW RESIDUAL OXYGEN DEMAND 'ROD'  DATA (1=YES, O=N
      O)",K8
      :PRINT HEX(030A)
      :IF K8=0  THEN  520
 490 PRINT TAB(3);"SEGMENT";TAB(15);"SEGMENT ROD (mg/l)"
 500 FOR I=1  TO NO
      :PRINT TAB(5);I;TAB(15);
      :INPUT SO(I)
      :NEXT I
 510 DATA SAVE DC #3,SO()
      :GOTO  530
 520 DATA LOAD DC #3,SO()
 530 PRINT HEX(03);TAB(25);"TRIBUTARY (river) DATA INPUT"
      :GOSUB 1830
 540 INPUT "UPSTREAM ---  FLOW ( m↑3 )",Q1
      :Q=Q1
      :PRINT
      :INPUT "UPSTREAM ---   DO ( mg/l )",C1(2)
      :PRINT
      :INPUT "UPSTREAM ---  BOD ( mg/l )",C1(1)
      :GOSUB 1830
 550 PRINT TAB(20);"SOURCE WATER (ocean) DATA INPUT"
      :GOSUB 1830
 560 INPUT "OCEAN ---  DO ( mg/l )",C2(2)
      :PRINT
```

```
     :INPUT "OCEAN ---  BOD ( mg/l )",C2(1)
570 GOSUB 1820
580 Q9=Q1
     :Q(1)=Q1
590 REM ****  ADDITIONAL POINT SOURCES OR OTHER FRESHWATER IN
     FLUENCES
     :REM ****  A9=COUNTER FOR ADDITIONAL TRIBUTARIES ****
     :A9=1
600 MAT C4=ZER
610 REM %*** POINT SOURCE DATA ***********
620 PRINT HEX(030A);TAB(25);"POINT SOURCE DATA INPUT";HEX(0D0
     A)
     :GOSUB 1830
630 PRINT "# ";A9;TAB(8);
     :PRINT "POINT SOURCE ENTERS INTO WHICH SEGMENT (1-15)"
     :PRINT TAB(22);"if end enter '0'  ";
     :INPUT N
     :IF N=0  THEN  740
640 X=N
650 PRINT HEX(0A);TAB(8);
     :INPUT "POINT SOURCE  ---  FLOW ( M↑3 ) ",Q4
     :PRINT HEX(0A);TAB(8);
     :INPUT "POINT SOURCE  ---   DO ( mg/l ) ",C4
     :PRINT HEX(0A);TAB(8);
     :INPUT "POINT SOURCE  ---  BOD ( mg/l ) ",L4
660 REM %*** TRIBUTARY DATA INPUT ********
670 C4(1,N)=(Q4*L4+Q(N)*C4(1,N))/(Q4+Q(N))
680 C4(2,N)=(Q4*C4+Q(N)*C4(2,N))/(Q4+Q(N))
690 REM %********************************
700 Q(N)=Q(N)+Q4
710 Q9=Q9+Q4
720 A9=A9+1
730 GOTO  620
740 PRINT HEX(030A0A0A)
750 REM *** CONCENTRATION AT INTERFACE OF SEGMENT BOUNDARIES
     :A0=.5
     :B0=.5
     :REM ***  X0 IS THE LENGTH BETWEEN NODES
760 INPUT "NEW Diffusion Coefficients (1=YES, 0=NO)",K9
     :PRINT HEX(030A)
770 IF K9=1  THEN  800
780 DATA LOAD DC #2,E0()
790 GOTO  810
800 PRINT
     :FOR I=1  TO 16
     :INPUT "DIFFUSION COEFFICIENTS",E0(I)
     :NEXT I
810 MAT C=ZER
820 F=1/86400
830 FOR I=1  TO 2
840 Q1=Q(1)
     :Q2=Q(1)
```

```
 850 E1=E0(1)
      :E2=E0(2)
 860 A1=A0(1)
      :A2=A0(2)
 870 N=1
 880 V=V0(N)
 890 T5=T(1)-20
 900 REM % *** CALC OF DEOXYGENATION COEFF. ***
      :K(1)=F*K1*1.047↑T5
 910 REM % *** CALC OF REAERIATION COEFF. *****
      :U=3.2808*(Q1+Q2)/(A1+A2)
      :D=3.2808*H(I)
 920 REM % *** CORRECT REAERIATION COEFF. *****
      :K(2)=F*(2.3*3.3*U/(D↑1.33)+(.384*W1↑.5-.088*W1+.0029*W1
      ↑2)/(H1(I)))
      :K(2)=K(2)*1.025↑T5
 930 A(2,1)=(Q1*B0)-(Q2*A0)-((E1*A1)/X0(N))-((E2*A2)/X0(N+1))-
      K(I)*V
 940 A(3,1)=-Q2*B0+E2*A2/X0(N+1)
 950 Y(1)=-Q1*C1(I)*A0-E1*A1*C1(I)/X0(N)+(I-1*(K(1)*C(1,1)-K(2
      )*C0(1))*V(I))
 960 Y(1)=-Q1*C1(I)*A0-E1*A1*C1(I)/X0(N)+(I-1*C(1,1)-K(2)*C0(1
      )*V(I))
 970 A1=A2
      :Q1=Q2
 980 REM % *** MODEL COMPUTATIONS AT NODES ****
 990 FOR N=2  TO N0-1
1000 E2=E0(N+1)
1010 REM *** FLOW COMING IN AT NODE (Q(N))
      :Q2=Q1+Q(N)
1020 A2=A0(N+1)
1030 V=V0(N)
1040 T5=T(N)-20
1050 U=3.2808*(Q1+Q2)/(A1+A2)
      :D=3.2808*H(N)
1060 K(1)=F*K1*1.047↑T5
1070 K(2)=F*(2.3*3.3*U/(D↑1.33)+(.384*W1↑.5-.088*W1+.0029*W1↑2
      )/(H1(I)))
      :K(2)=K(2)*1.025↑T5
1080 A(1,N)=Q1*A0+E1*A1/X0(N)
1090 A(2,N)=(Q1*B0)-(Q2*A0)-((E1*A1)/X0(N))-((E2*A2)/X0(N+1))-
      (K(I)*V)
1100 A(3,N)=-Q2*B0+E2*A2/X0(N+1)
1110 Y(N)=-Q(N)*C4(I,N)+(I-1)*(K(1)*C(1,N)-K(2)*C0(N)+F*S0(N))
      *V
1120 REM PRINT N,Q(N)*C4(I,N),K(1)*C(1,N)*V,K(2)*C0(N)*V
1130 A1=A2
      :Q1=Q2
      :E1=E2
1140 NEXT N
1150 Q2=Q1+Q(N0)
1160 A2=A0(N0+1)
```

```
1170 E2=E0(NO+1)
1180 T5=T(NO)-20
1190 V=V0(NO)
1200 K(1)=F*K1*1.047↑T5
1210 K(2)=F*(2.3*3.3*H(NO)+(.384*W1↑.5-.088*W1+.0029*W1↑2)/(H1
      (I)))
      :K(2)=K(2)*1.025↑T5
1220 A(1,NO)=Q1*A0+E1*A1/X0(NO)
1230 A(2,NO)=(Q1*B0)-(Q2*A0)-((E1*A1)/X0(NO))-((E2*A2)/X0(NO+1
      ))-K(I)*V
1240 Y(NO)=-Q(NO)*C4(I,NO)+(I-1)*(K(1)*C(1,N)-K(2)*C0(N)+F*S0(
      N))*V+Q2*C2(I)*B0-E2*A2*C2(I)/X0(NO+1)
1250 GOSUB 1620
1260 FOR M= 1  TO NO
      :C(I,M)=Z(M)
      :NEXT M
1270 REM FOR M=1 TO NO
1280 REM PRINTUSING 1070,M,Z(M)
1290 REM        ##                     ##.## (mg/l) BOD
1300 REM  NEXT M
1310 NEXT I
1320 FOR N=1  TO NO+1
1330 C(1,N)=0
      :C(2,N)=0
1340 NEXT N
1350 GOSUB 1400
1360 SELECT PRINT 215(80)
      :PRINT HEX(0C0A0A0A0A0A)
      :GOSUB 1400
      :GOSUB 1520
      :SELECT PRINT 005
1370 DATA SAVE DC CLOSE ALL
1380 Q1=Q
1390 END
1400 REM %*** PRINT EXPECTED DO CONC *****
1410 PRINT TAB(15);HEX(0E);D$
      :PRINT HEX(0A0A)
1415 GOSUB 3000
1420 PRINT TAB(39);"PREDICTED"
1425 GOSUB 3000
1430 PRINT TAB(23);"SEGMENT";TAB(34);"SEGMENT AVERAGED D.O.";
      HEX(0D0A)
1435 GOSUB 3000
1440 PRINT E$
1445 GOSUB 3000
      :PRINTUSING 1475
1450 FOR M=1  TO NO
1455 GOSUB 3000
1460 PRINTUSING 1470 ,M,ROUND(Z(M),1)
1470 %*     ##           ##.#  mg/l           *
1475 %*                                       *
1479 GOSUB 3000
```

PROGRAM LISTING

```
     :PRINTUSING 1475
1480 NEXT M
1490 GOSUB 3000
     :PRINT E$
1494 PRINT HEX(0C0A0A0A0A0A)
1500 REM %*** END OF PRINT ROUTINE *******
1510 RETURN
1520 PRINT TAB(17);HEX(0E);"MODEL INPUT"
     :PRINT
1530 PRINT TAB(51);
     :PRINTUSING 3120
     :PRINT TAB(15);
     :PRINTUSING 3130
     :FOR I=1  TO 15
     :PRINT TAB(15);
     :PRINTUSING 3100 ,I,S(I),T(I),E0(I),S0(I)
     :NEXT I
1532 PRINT TAB(52);
     :PRINTUSING 3110 ,E0(16)
1535 PRINT TAB(7);HEX(0A0A0E);"DEOXYGENATION RATE =";K1
     :PRINT HEX(0A0A0E);TAB(20);"DATA"
1540 PRINT TAB(32);HEX(0A);"TRIBUTARY    PUGET SOUND    POINT
     SOURCE"
     :PRINT TAB(15);"SEGMENT";TAB(65);X
     :PRINT TAB(15);"FLOW (M↑3/SEC) ";TAB(32);
     :PRINTUSING 3140 ,Q,Q4
     :PRINT TAB(15);"DO (MG/L)       ";TAB(32);
     :PRINTUSING 3150 ,C1(2),C2(2),C4
     :PRINT TAB(15);"BOD (MG/L)      ";TAB(32);
     :PRINTUSING 3160 ,C1(1),C2(1),L4
1560 PRINT TAB(17);HEX(0A0E);"WIND SPEED "
     :PRINT TAB(35);"  mph = ";W2
     :PRINT TAB(35);" kmph = ";ROUND(W1,1)
1600 RETURN
1610 REM %*** SOLVE MATRIX COEFFICIENT ***
1620 V(1)=A(2,1)
1630 W(1)=Y(1)
1640 FOR J=2  TO NO
1650 V(J)=A(2,J)-A(1,J)*A(3,J-1)/V(J-1)
1660 W(J)=Y(J)-A(1,J)*W(J-1)/V(J-1)
1670 NEXT J
1680 REM COMPUTE LAST VALUE
     :Z(NO)=W(NO)/V(NO)
1690 REM GOES BACKWARD TO COMPUTE UNKNOWNS
     :FOR J1=1  TO NO-1
1700 J=NO-J1
1710 Z(J)=(W(J)-A(3,J)*Z(J+1))/V(J)
1720 NEXT J1
1730 RETURN
1740 REM %*** GOSUB TO CALCULATE SAT DO **
1750 T=T(I)
     :P1=1
```

```
1760 C9=((S(I)-.03)/1.805)*1000
1770 D1=(14.6214-.4026*T+6.8516E-03*T↑2+2.2619E-04*T↑3-2.4998E
      -05*T↑4+8.5254E-07*T↑5-1.0513E-08*T↑6)*P1
1780 F1=1.6507E-02-5.4067E-04*T+1.1483E-07*T↑2+1.4165E-06*T↑3-
      1.1197E-07*T↑4+4.1320E-09*T↑5-5.6092E-11*T↑6
1790 CO(I)=D1-F1*C9/100
1800 CO(I)=(INT(CO(I)*100+.5))/100
1810 RETURN
1820 REM *** LINE PRINT AND PAUSE SUBROUTINE ****
      :PRINT E1$
      :PRINT HEX(0A0A);
      :INPUT "PRESS (EXEC) TO CONT.",B4
      :RETURN
1830 REM *** LINE PRINT SUBROUTINE ****
      :PRINT E1$
      :PRINT HEX(0A0A)
      :RETURN
1840 REM %*** DATA FOR MODEL CONSTANTS ***
1850 REM ************ NUMBER OF SEGMENTS ****************
      :DATA 15
1860 REM ************ 'U/S' SEGMENT DEPTH ( METERS ) *********
      *******
      :DATA 2,3,2.3,4.6,3.7,3,4.3,4.8,6.1,7.6,6.7,4.6,4.3,6.7,
      9.1
1870 REM ******* U/S CROSS-SECTIONAL AREA FOR EACH SEGMENT ( M
      ETERS ↑2 ) ******
      :DATA 118,270,278,699,677,645,1058,1330,2013,2918,2452,2
      525,5698,10995,20111,39627
1880 REM ************ LENGTH OF EACH SEGMENT ( METERS ) ******
      **********
      :DATA 100,100,100,100,100,100,100,123,150,200,473,869,12
      80,3612,3932,3932
1890 REM ************ U/S WIDTH OF EACH SEGMENT ( METERS ) ***
      *************
      :DATA 59,90,121,152,183,215,246,277,330,384,366,549,1325
      ,1641,2210
1900 REM ************ SEGMENT VOLUME (m↑3)  *****************
      *************
      :DATA 1.86E4,2.80E4,4.71E4,6.95E4,6.67E4,8.41E4,1.19E5,2
      .03E5,3.67E5,5.36E5,1.22E6,3.62E6,1.04E7,5.49E7,1.18E8
1910 REM ************ MEAN SEGMENT DEPTH ( METERS ) **********
      ******
      :DATA 2.5,2.65,3.45,4.15,3.35,3.65,4.55,5.45,6.85,7.15,5
      .65,4.45,5.5,7.9,13.8
3000 PRINT TAB(20);
      :RETURN
3100 %  ##        ##.#        ##.#          ###.#        #.#
3110 % ###.#
3120 %Diffusion         ROD
3130 %SEGMENT  Salinity   Temperature    Coefficient      Data
3140 %####.##                          ##.##
3150 %  ##.#         ##.#           ##.#
```

PROGRAM LISTING

```
3160 %  ####           ####            ####
4000 DEFFN'30"F$=";HEX(22);"MODEL";HEX(223A);"SCRATCH R F$";
      HEX(OD)
4010 DEFFN'31 "SAVE DC R$(F$)F$";HEX(OD)
4020 DEFFN'14"SELECT LIST 005(80)";HEX(OD)
4030 DEFFN'15"SELECT LIST 215(132)";HEX(OD)
4040 DEFFN' 0 "LIST SD1510,";HEX(OD)
```

LINE NUMBER CROSS-REFERENCE

```
 360 - <  1> --   350
 450 - <  1> --   390
 460 - <  1> --   440
 520 - <  1> --   480
 530 - <  1> --   510
 620 - <  1> --   730
 740 - <  1> --   630
 800 - <  1> --   770
 810 - <  1> --   790
1400 - <  2> --  1350 1360
1470 - <  1> --  1460
1475 - <  2> --  1445 1479
1520 - <  1> --  1360
1620 - <  1> --  1250
1740 - <  1> --   420
1820 - <  1> --   570
1830 - <  5> --   410  530  540  550  620
3000 - <  7> --  1415 1425 1435 1445 1455 1479 1490
3100 - <  1> --  1530
3110 - <  1> --  1532
3120 - <  1> --  1530
3130 - <  1> --  1530
3140 - <  1> --  1540
3150 - <  1> --  1540
3160 - <  1> --  1540
```

VARIABLE CROSS-REFERENCE

```
A0      - <  9> --  250  750  930  950  960 1080 1090 1220
                   1230

A1      - < 12> --  860  910  930  950  960  970 1050 1080
                   1090 1130 1220 1230

A2      - < 13> --  860  910  930  940  970 1020 1050 1090
                   1100 1130 1160 1230 1240

A9      - <  4> --  590  630  720  720

B0      - <  7> --  750  930  940 1090 1100 1230 1240

B4      - <  1> -- 1820

C       - <  1> --  810

C4      - <  5> --  120  600  650  680 1540

C9      - <  2> -- 1760 1790

D       - <  4> --  910  920 1050 1070

D1      - <  2> -- 1770 1790

E1      - <  9> --  850  930  950  960 1080 1090 1130 1220
                   1230

E2      - < 10> --  850  930  940 1000 1090 1100 1130 1170
                   1230 1240

F       - <  9> --  820  900  920 1060 1070 1110 1200 1210
                   1240

F1      - <  2> -- 1780 1790

H       - <  1> --  240

H1      - <  1> --  290

I       - < 49> --  420  420  420  420  420  420  500  500
                    500  500  800  800  800  830  910  920
                    930  950  950  950  950  960  960  960
                    960 1070 1090 1110 1110 1210 1230 1240
                   1240 1240 1240 1260 1310 1530 1530 1530
                   1530 1530 1530 1530 1750 1760 1790 1800
                   1800

I9      - <  3> --  310  350  360

J       - < 21> --  460  460  460 1640 1650 1650 1650 1650
```

VARIABLE CROSS-REFERENCE

```
                          1650 1660 1660 1660 1660 1660 1670 1700
                          1710 1710 1710 1710 1710

J1       - <   3> -- 1690 1700 1720

K1       - <   5> --  190  900 1060 1200 1535

K8       - <   2> --  480  480

K9       - <   4> --  380  390  760  770

L4       - <   4> --  120  650  670 1540

M        - <   8> -- 1260 1260 1260 1260 1450 1460 1460 1480

MO       - <   3> --  120  180  200

N        - <  48> --  630  630  640  670  670  670  670  680
                      680  680  680  700  700  870  880  930
                      930  940  950  960  990 1000 1010 1020
                     1030 1040 1050 1080 1080 1090 1090 1090
                     1100 1100 1110 1110 1110 1110 1110 1110
                     1140 1240 1240 1240 1320 1330 1330 1340

NO       - <  29> --  230  420  460  500  990 1150 1160 1170
                     1180 1190 1210 1220 1220 1230 1230 1230
                     1240 1240 1240 1240 1260 1320 1450 1640
                     1680 1680 1680 1690 1700

P1       - <   2> -- 1750 1770

Q        - <   4> --  120  540 1380 1540

Q1       - <  20> --  120  540  540  580  580  840  910  930
                      950  960  970 1010 1050 1080 1090 1130
                     1150 1220 1230 1380

Q2       - <  13> --  840  910  930  940  970 1010 1050 1090
                     1100 1130 1150 1230 1240

Q4       - <   9> --  120  650  670  670  680  680  700  710
                     1540

Q9       - <   3> --  580  710  710

T        - <  13> -- 1750 1770 1770 1770 1770 1770 1770 1780
                     1780 1780 1780 1780 1780

T5       - <   9> --  890  900  920 1040 1060 1070 1180 1200
                     1210

U        - <   4> --  910  920 1050 1070

V        - <   8> --  880  930 1030 1090 1110 1190 1230 1240
```

VARIABLE CROSS-REFERENCE

```
VO      - <   1> --  280

W       - <   1> --  270

W1      - <  11> --  210  920  920  920 1070 1070 1070 1210
                    1210 1210 1560

W2      - <   3> --  210  210 1560

X       - <   2> --  640 1540

XO      - <   1> --  260

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

A()     - <  14> --  100  930  940 1080 1090 1100 1220 1230
                    1620 1650 1650 1650 1660 1710

AO()    - <   5> --  110  860  860 1020 1160

C()     - <   8> --  100  950  960 1110 1240 1260 1330 1330

CO()    - <  11> --  100  420  430  450  950  960 1110 1240
                    1790 1800 1800

C1()    - <   9> --  120  540  540  950  950  960  960 1540
                    1540

C2()    - <   7> --  120  560  560 1240 1240 1540 1540

C4()    - <   7> --  120  670  670  680  680 1110 1240

EO()    - <   9> --  100  780  800  850  850 1000 1170 1530
                    1532

H()     - <   4> --  100  910 1050 1210

H1()    - <   4> --  100  920 1070 1210

K()     - <  23> --  110  900  920  920  920  930  950  950
                     960 1060 1070 1070 1070 1090 1110 1110
                    1200 1210 1210 1210 1230 1240 1240

Q()     - <  15> --  100  460  580  670  670  680  680  700
                     700  840  840 1010 1110 1150 1240

S()     - <   6> --  110  420  430  450 1530 1760

SO()    - <   7> --  100  500  510  520 1110 1240 1530

T()     - <   9> --  110  420  430  450  890 1040 1180 1530
```

VARIABLE CROSS-REFERENCE

```
                        1750

V()     - <   9> --   110  950  960 1620 1650 1650 1660 1680
                     1710

VO()    - <   4> --   110  880 1030 1190

W()     - <   6> --   110 1630 1660 1660 1680 1710

XO()    - <  14> --   110  930  930  940  950  960 1080 1090
                     1090 1100 1220 1230 1230 1240

Y()     - <   7> --   100  950  960 1110 1240 1630 1660

Z()     - <   6> --   110 1260 1460 1680 1710 1710

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

A$      - <   5> --   200  320  320  320  320

A1$     - <   2> --   160  320

B$      - <   5> --   200  330  330  330  330

B1$     - <   2> --   160  330

C$      - <   5> --   200  340  340  340  340

C1$     - <   2> --   160  340

D$      - <   3> --   100  170 1410

E$      - <   4> --   130  140 1440 1490

E1$     - <   4> --   130  140 1820 1830

MO$     - <   4> --   200  320  330  340
```

MARKED SUBROUTINE CROSS-REFERENCE

```
DEFFN'  0<   1> -- 4040
DEFFN' 14<   1> -- 4020
DEFFN' 15<   1> -- 4030
DEFFN' 30<   1> -- 4000
DEFFN' 31<   1> -- 4010
```

SUMMARY

TEXT LINES = 202

TEXT STATEMENTS = 337

LINE NUMBERS = 25

VARIABLES = 76

MARKED SUBROUTINES = 5