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M E M O R A N D U M
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To: Dave Nunnallee and John Glynn

From: Tim Determan and Will Kendra

Subject: Post-Upgrade Receiving Water Study of the Town of Friday Harbor Sewage Treatment Plant

ABSTRACT

Between autumn 1983 and spring 1985, the Friday Harbor Marina was expanded two-fold. Concurrently, the Friday Harbor Sewage Treatment Plant (STP) was upgraded and the discharge relocated. A survey conducted in August 1985 showed that significant improvements in the effluent mixing zone have occurred. During a May 1983 survey, fecal coliform levels associated with the STP discharge were a significant water quality problem in the marina. Ammonia and total phosphorus levels at the discharge point were above levels found elsewhere in Friday Harbor. Sewage solids were visible in the discharge boil. In August 1985, fecal coliform levels in the new mixing zone were equal to a nearby control site. The discharge could not be located using other water quality parameters or a dye tracer dropped into the effluent. However, fecal coliform levels in the marina remained high, likely due to expanded marina use and other possible shoreline sources.

INTRODUCTION

The Water Quality Investigations Section of the Washington Department of Ecology (Ecology) was requested to evaluate the effects of the upgraded Friday Harbor STP effluent on the receiving waters. Singleton and Joy (1983) performed a receiving water study in Friday Harbor prior to the upgrade. They concluded that fecal coliform (FC) contamination, the predominant water quality problem in Friday Harbor, resulted primarily from the Friday Harbor STP discharge. At that time, the STP provided primary treatment. Sewage flows were subject to surges due to an upstream pump station which disrupted effluent treatment and chlorination (Heffner, 1983). The discharge was easily located as a surface boil rising from the diffuser in about 30 feet of water (Figure 1).

Problems with waste collection and treatment in Friday Harbor were studied by Kramer, Chin and Mayo, Inc. (1977). One proposed alternative was ultimately accepted: upgrading the treatment process to secondary and connecting wastewater from the UW Friday Harbor laboratories to the STP. The location of the discharge in Friday Harbor was not to be changed. Funding for the upgrade, however, was not forthcoming because of low priority on the Referendum 39 list (D. Nunnallee, personal communication).

The U.S. Army Corps of Engineers (1981) proposed an expansion of the Friday Harbor marina. Ecology asked that the discharge be moved outside the perimeter of the proposed new marina (Nunnallee, 1982) in order to exclude primary effluent from within the marina. The outfall was to be extended 700 feet and included a four-port diffuser 45 feet long (Figure 2) at a depth of -60 feet (msl). Initial dilution was estimated to be 110:1 at peak flow and 120:1 under dry-weather flow (Esvelt Engineering, 1984). The plume was not expected to surface. The marina expansion and outfall extension were completed by November 1984 (M. Sly, Port Harbormasters Office, personal communication). In the interim, a grant was approved for the STP upgrade. This work was completed by winter 1984-85 (D. Nunnallee, personal communication).

Friday Harbor and the San Juans are classified as Class AA marine waters (Washington Dept. of Ecology, 1980). Water quality standards for this classification are shown in Appendix A.

The objectives for this study were as follows:

1. To document the present water quality in Friday Harbor and make comparisons between pre- and post-upgrade conditions.

2. To determine the effects of the improved STP discharge on water quality within the mixing zone and to compare conditions with water quality within the marina, along developed shorelines, and in mid-San Juan Channel (a control site).

The receiving water study was performed in conjunction with a Class II inspection of the Friday Harbor STP (Heffner, in prep.).

METHODS

Vertical-profile sampling was carried out at ten deepwater sites (Figure 2). Three stations (1, 8, and 9) were located in the marina. Station 1 was the site of the 1983 discharge. Station 2 was located among eight to ten anchored boats (including several large tugs). Station 4 served as a control site during this and the 1983 study. Station 5 was located near the Washington State Ferry Terminal. Four more sites (7A - D) were set up in the assumed vicinity of the new discharge point. Station 7A was near the discharge point shown in Plate 2 of U.S. Army Corps of Engineers (1981). However, several other points were added because the actual discharge point could not be located with fluorescent dye. According to Harbormaster Ray Chestnutt, the discharge may in fact lie near Station 7D.

Figure 3 shows the tidal behavior and approximate sampling times. The study design called for sampling the marina sites at a time when receding tidal currents placed the marina upcurrent of the discharge. This minimized STP effects in the marina and provided a basis for separating discharge effects from marina effects. Marina sampling was done on the morning of August 13.

Discharge zone sampling occurred the morning of August 14. Sampling was done during lower low slack water when initial dilution and downcurrent dispersion were minimal. A 1m drogue was used to track water motion. Five shoreline surface sites were then sampled for fecal coliforms. These sites were used to detect shoreline influences. The control site (Station 4) was sampled both days under similar conditions in order to estimate comparability. Figure 3 shows the tidal behavior and approximate sampling times.

Due to the typically high variability of FC data, duplicate surface samples were taken at each station and a geometric mean calculated for each pair. Besides fecal coliforms, laboratory analyses included nutrients (five forms) and turbidity. Samples at depth were taken with a 2L Kemmerer. Samples were placed on ice and returned to the EPA/Ecology laboratory at Manchester within 24 hours. A Hydrolab II system was used to measure temperature, salinity, dissolved oxygen, and pH. The system was calibrated prior to the survey and re-checked afterward. Instrument drift for all variables was insignificant. Water clarity was estimated with a 20 cm Secchi disk. Appendix A discusses each parameter, its method of analysis, and the appropriate water quality standard.

Seawater density was determined using the method of Bailek (1966). In shallow waters, density is a function of salinity and temperature and is reported as sigma-t:

$$\text{sigma-t } (gcm^{-3}) = (\text{density}_{s,t} - 1.000) \times 10^3$$

where: Density (s,t) is at field salinity (s) and temperature (t)
and: 1.000 is the density of water with no salinity and temperature equal to 25°C.

Density was used to measure the degree of vertical stratification in the water column.

RESULTS AND DISCUSSION

Fecal coliform data from this survey are compiled in Appendix B. All other data are in Appendix C. Table 1 summarizes the fecal coliform in terms of compliance with the water quality standards. Figure 4 shows FC data for individual stations. The results demonstrate that during the survey surface waters within the mixing zone complied fully with the water quality standard and were comparable with levels found at Station 4, the control site.

Waters within the marina failed to comply with either part of the FC standard. Possible sources for contamination within the marina are illegal discharge of on-board holding tanks, accidental spillage of sewage at pump-out facilities, and waste from pets left on piers and docks. The degree of violation was small. Provision for handling wastes from on-board pets, enforcement of holding tank discharge prohibitions, and increased emphasis on education about pollution (posting signs, etc.) may be helpful.

Figure 2 shows the motion of the drift drogue at the time of sampling in the discharge zone (August 14). At 0715 at Station 7C, the current was observed to be moving eastward toward the mouth of the marina. At 0740 the drogue was placed at Station 7A. It moved about 60 feet WNW through the mouth of the marina and turned north. By 0800 it came to rest against the inside of the breakwater. The drogue was relaunched at 7d. Between 0806 and 0926, the drogue drifted north, looped westward, reversed direction, and moved toward the marina entrance. The drogue behavior suggests that at low slack tide, effluent from the STP may remain in the vicinity of the diffuser. Under these conditions, a buildup of pollutants could occur in the event of an STP failure.

Average FC concentration at Station 5 (located between the ferry dock and the San Juan Marina fuel facility) was 134 FC per 100 mL (Figure 4) which suggests a significant source nearby. On the other hand, Station 2 (located among a fleet of anchored boats of varying size) had barely detectable FC levels.

Most shoreline sampling points complied with the standard. Contamination was found at Station X near the foot of the San Juan Marina dock (Figures 2 and 4). A flowing drainpipe was seen onshore within 50 feet of the sampling point. Due to navigational hazards, a drain sample was not collected. Station Y was located below homes and apartments perched above a steep rock shoreline east of the ferry terminal. Several drain lines were seen running down the cliff face into subtidal waters. Fecal coliform concentrations here were moderately high (13 FC/100 mL, Figure 4) compared to other shoreline sites. A more detailed shoreline survey may be in order.

All data from this survey (Appendices B and C) and those from the May 1983 study (Appendix D) were pooled into groups of stations representing use categories (mixing zone, marina, etc.). Table 2 describes which stations from each survey were pooled for each use area. Group means and standard deviations were determined for each water quality parameter, use area, and depth (0 and 10m). These are shown graphically in Figure 5 (note that the mixing zone in 1983 is at a different location than in 1983). These graphs were used to detect differences related to STP/Marina modifications. Also, differences due to season (May versus August), years (1983 versus 1985), or depth (0 versus 10 m) might be inferred.

Singleton and Joy (1983) concluded that high FC concentrations, the predominant water quality problem in Friday Harbor, resulted mainly from the former STP discharge. Figure 5a suggests that the present discharge design has nearly eliminated STP-derived FC from the surface waters of Friday Harbor, but FC concentrations in the marina remain high. If marina contamination was due mainly to the STP discharge in 1983, then its elimination as a source may have been balanced in part by the increase in population density in the marina. The design capacity in 1983 was 250 slips, whereas during our August 1985 survey, over 550 boats were moored overnight (Ray Chestnutt, Harbormaster, personal communication).

Ammonia (NH_3-N) and total phosphate (T-PO_4-P) levels in surface mixing zone waters were somewhat higher in 1983 than in 1985 (Figure 5b, c). At present, it appears that nutrient concentrations in waters of different locations (including ambient station SJI001 in mid-San Juan Channel) are nearly equal. Improved mixing in the new mixing zone probably accounts for lower concentrations in 1985.

Water clarity was generally better in August 1985 than in May 1983. The previous study cited a visible boil with toilet paper and other sewage solids over the discharge point. Nothing like this was visible in the present discharge zone. Both Secchi readings and turbidity (Appendix B) were significantly improved.

Neither the 1983 nor the 1985 discharges appeared to significantly affect D.O., pH, temperature, or salinity in the mixing zone. These parameters were influenced more by depth and seasonal factors. D.O. was slightly higher at the surface than at 10m during both surveys and generally higher in May 1983 than in August 1985. Similar results from the ambient station suggest that this was due to either cooler water or higher primary production during the month of May.

Salinity at the ambient site was evenly distributed with depth. Monthly averages for May and August for the period of record are nearly equal (Figure 5d). Ambient-site overall average salinity for May was higher than salinity in Friday Harbor measured during the May 1983 survey. The overall average salinity for August at the ambient site was higher than that in Friday Harbor during the August 1985 survey. Salinity in Friday Harbor was generally lower at all depths in August 1985, with a somewhat stronger vertical gradient than in May 1983.

During the 1983 study, temperatures were nearly equal at all areas (including the ambient site) with little vertical gradient. In August 1985, seasonal heating produced higher temperatures and a slight temperature gradient.

Figure 6 shows salinity, temperature, and density (sigma-t) with depth at two stations during the 1985 survey. Stratification was slight and nearly linear with depth. This suggests that the waters of Friday Harbor tended to be well mixed. Salinities at all depths at the control station (Station 4) on August 14 were slightly higher than on August 13 (Appendix B), but the relative gradients from both days are similar. There did not appear to be a substantial amount of freshwater at any depth in the discharge zone. This suggested a well-mixed effluent.

CONCLUSIONS

The present mixing zone of the Friday Harbor STP complied fully with FC criteria in the state Water Quality Standards during a survey in August 1985. Concentrations of FC and other water quality parameters in the vicinity of the discharge point were similar to those at a nearby control site. Conditions in the present mixing zone contrast sharply with those found by Singleton and Joy (1983). At that time, the mixing zone (located farther inshore) contained levels of FC, total phosphorus, and ammonia that were higher than other areas of Friday Harbor, and certainly higher than levels encountered anywhere in Friday Harbor in August 1985.

During the May 1983 study, sewage solids were clearly visible at the surface over the discharge. This was not the case in this study. In fact, despite tagging of STP wastewater with dye on three occasions, we were unable to locate an effluent plume in the vicinity of the new outfall site. Thus, treatment improvements (extension of the outfall line and addition of a diffuser) resulted in compliance with water quality standards during the August 1985 survey.

Despite the STP improvements, water quality in the marina has changed little. This could be due to expansion and intensified use of the marina and contributions from several shoreline sources. Further improvement in Friday Harbor water quality will result when these sources are identified and stopped. Education of boaters concerning disposal of shipboard and pet wastes also could be helpful.

TAD:WK:cp

Attachments

cc: Dick Cunningham
Lynn Singleton
Ray Chestnutt

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Table 1. Summary of compliance with water quality standards for fecal coliforms[1] in Friday Harbor on August 13 and 14, 1985.

Use Area	Date	No. of Samples	Geometric Mean (FC/100 mL)	Percent Exceeding 43 FC/100 mL	Meets Applicable Standards, Part 1	Meets Applicable Standards, Part 2[2]
Control Site (Station 4)	8/13 8/14	4	1	0	Yes	Yes
Mixing Zone (Stations 7A - D)	8/14	8	3	0	Yes	Yes
Marina Sites (Stations 1, 8, 9)	8/13	6	20	33	No	No
Other Deep Sites (Stations 2, 5)	8/13	4	14	50	Yes	No
Nearshore Sites (Stations U, V, W, X, Y)	8/14	10	5	20	Yes	No
Friday Harbor (all stations)	8/13 8/14	32	6	19	Yes	No

[1]Taken from Chapter 173-201 Washington Administrative Code (Washington State Department of Ecology)
Part 1: Geometric means not exceeded 14 FC per 100 mL; and
Part 2: Ten percent of samples not to exceed 43 FC per 100 mL.

[2]When the number of samples is less than ten, the decision is provisional only.

Table 2. Supplementary information on areas of similar use in Friday Harbor during the surveys of 1983 and 1985.

	Control Stations		Mixing Zone		Marina Sites		Ecology Ambient Station	
Month/Year	5/1983	8/1985	5/1983	8/1985	5/1983	8/1985	5/1983	8/1985
time (approx.)	1700	1000 & 1240	1130 & 1645	0745	1710	1000	late a.m.	late a.m.
Stations	4[a]	4[b]	1, drogue positions DR-1, DR-2[a]	7A, 7B, 7C, 7D[b]	2, 3[a]	1, 8 ,9[b]	SJI001 (San Juan Channel near Reid Rock)[c]	

[a]Figure 1

[b]Figure 2

[c]Data used for Figure 5 were for the period of record (1975 through 1985)

Appendix A. Parametric coverage, rationale, and associated water quality standards for the Friday Harbor STP receiving water study of August 1985. Water quality standards are contained in Chapter 173-201 of the Washington Administrative Code (Washington State Department of Ecology, 1980).

Parameter	Method	Reason for Sampling	Water Quality Standard (Class AA)
Fecal Coliform Bacteria in Water (FC/100 mL)	APHA (1980)	Indicator of presence of intestinal wastes from humans and other animals.	Freshwater: not to exceed a geometric mean of 50 FC per 100 mL, with not more than 10 percent of samples to exceed 100 FC/100 mL. Seawater: not to exceed a geometric mean of 14 FC per 100 mL, with not more than 10 percent of samples to exceed 43 FC/100 mL.
Temperature (°C)	Temperature function on Hydrolab Surveyor II	Used with salinity to determine water density (sigma-t) and with oxygen to determine percent saturation. Temperature also affects gas solubility and rates of biological processes.	Not to exceed 16.0°C (freshwater) or 13.0°C (seawater) due to human activities. When natural conditions exceed 16.0°C (freshwater) or 13.0°C (seawater), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C.
Salinity (o/oo)	Salinity function on Hydrolab Surveyor II	Used to trace passage of freshwater through marine waters. Also affects mixing rates and density distribution in water column and solubility of dissolved oxygen.	In brackish waters of estuaries, where fresh and marine water quality criteria differ within the same classification, the criteria shall be interpolated on the basis of salinity; except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater.
Dissolved Oxygen (mg/L)	Oxygen function on Hydrolab Surveyor II	Elevated, relatively constant oxygen levels are essential for stable aquatic communities. Highly variable levels downcurrent from a source may be indicative of an organic load in excess of the ability of the system to assimilate it.	Freshwater: shall exceed 9.5 mg/L. Seawater: shall exceed 7.0 mg/L; when natural conditions (e.g., upwelling) depress D.O. near or below 7.0 mg/L, natural D.O. levels can be degraded by up to 0.2 mg/L by man-caused activities.

Appendix A. Continued.

Parameter	Method	Reason for Sampling	Water Quality Standard (Class AA)
Nutrients (mg/L) NO_3-N; NO_2-N; NH_3-N; O-PO_4-P; T-PO_4-P	EPA (1979); APHA (1980)	Inorganic nutrients are readily available for assimilation by algae and other aquatic plants. Excessive levels with abundant light may lead to massive algae production at the expense of other plants and animals. Ammonia (NH_3-N) is an immediate byproduct of the breakdown of urine and therefore may be useful to trace animal wastes in water.	Numerical standard in development. Excessive levels (0.02 mg/L) of un-ionized ammonia are toxic to freshwater organisms, but toxicity in marine waters has not been well studied (EPA, 1976; Willingham, et al., 1979). Un-ionized ammonia toxicity is a function of pH, temperature, and salinity.
pH (S.U.)	pH function on Hydrolab Surveyor II	pH affects the carbonic acid-carbon dioxide balance in water. pH also affects the activity of un-ionized ammonia, sulfide, and metals.	Shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (seawater) with man-caused variation within a range of less than 0.2 unit.
Turbidity (NTU)	Hach Turbidimeter	Measures water column transparency and light availability, and is an estimate of suspended material in water column. Turbidity is a function of the quantity and light scattering characteristics of the suspended material.	Not to exceed 5 NTU over background if background is 50 NTU or less, or have more than a 10 percent increase in turbidity when background turbidity is more than 50 NTU. Sufficient light is essential to aquatic plant growth. Excessive suspended material may stress plants and animals by light reduction or smothering.
Secchi Depth (m)	20 cm diameter Secchi disc lowered to depth of disappearance	Measures water column transparency and light availability, and is an estimate of suspended material in water column.	No numerical standard. Sufficient light is essential to aquatic plant growth. Excessive suspended material may stress plants and animals by light reduction or smothering.

Appendix B. Results of bacteriological sampling conducted at Friday Harbor on August 12-14, 1985. Units are fc/100 mL of sample. Fecal coliform counts of less than the minimum required for statistical confidence (20 fc/100 mL) are considered estimates.

Sampling Station	Date	Time	Sample 1	Sample 2	Geometric Mean($\bar{X}$)
Control Site					
4	8/13	1240	1	2	1.4
4	8/14	1000	<1	1	1.0
Mixing Zone Sites					
7A	8/14	0743	1	3	1.7
7B	8/14	0833	5	7	5.9
7C	8/14	0715	9	16	12.0
7D	8/14	0811	<1	1	1.0
Marina Sites					
1	8/13	0825	52	75	62.4
8	8/13	0842	16	19	17.4
9	8/13	0745	5	9	6.7
Other Deep Sites					
2	8/13	0903	<1	2	1.4
5	8/13	0803	120	150	134.2
Shoreline Sites					
U	8/14	1015	4	5	4.5
V	8/14	1026	<1	1	1.0
W	8/14	1035	<1	1	1.0
X	8/14	1055	57	71	63.6
Y	8/14	1100	10	16	12.6
Friday Harbor STP Effluent					
	8/13	0945	3	--	--
	8/13	1915	3	--	--
	8/14	0920	10	--	--

Appendix D. Results from Friday Harbor receiving water survey, May 1983.

			Field Analyses						Laboratory Analyses										Solids (mg/L)			
Station	Time	Flow (MGD)	Temperature	Secchi Disk (ft.)	Conductivity (mmhos/cm)	Dissolved Oxygen (mg/L)	Salinity (o/oo)	Turbidity (NTU)	pH (S.U.)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	Ammonia-N (mg/L)	Total Phos.-P (mg/L)	Orthophos.-P (mg/L)	Fecal Coliform (org/100 mL [MF])	Fecal Coliform (org/100 g [MPN])	BOD_5 (mg/L)	COD (mg/L)	Total	Total Non-Vol.	Total Susp.	TNVSS
1-S[1/]	1645		8.8	16.0	32.2	8.6	29.0	10	8.0	0.20	<0.01	0.14	0.08	0.06	170/4200[3,4/]							
-D[2/]			8.9		32.6	8.7	29.5	6	8.0	0.20	<0.01	0.02	0.05	0.03								
2-S	1700		8.9	19.0	32.1	8.7	29.0	3	8.0	0.20	<0.01	0.04	0.05	0.04	18[3/]							
-D			8.9		32.4	8.7	29.4	3	8.0	0.22	<0.01	0.02	0.05	0.03								
3-S	1720		9.0	18.5	32.1	8.7	28.9	3	8.0	0.22	<0.01	0.04	0.06	0.04	77							
-D			8.8		32.2	8.5	29.2	3	8.0	0.22	<0.01	0.02	0.04	0.03								
4-S	1710		9.6	19.0	32.2	8.8	29.1	3	8.0	0.21	<0.01	0.02	0.04	0.03	<1							
-D			8.8		32.4	8.6	29.3	4	8.0	0.21	<0.01	0.02	0.04	0.03								
5-S	1630		9.0	20.0	32.4	9.0	29.2	4	8.0	0.24	<0.01	0.02	0.04	0.03	<1							
-D			8.8		32.5	8.4	29.5	4	8.0	0.22	<0.01	0.02	0.04	0.03								
6-S	1615		9.0	20.0	32.2	8.7	29.2	1	8.0	0.22	<0.01	0.02	0.04	0.03	<1							
-D			8.6		32.5	8.3	29.6	6	7.9	0.24	<0.01	0.02	0.05	0.03								
X30																790[5/]						
X60																16,000[5/]						
DR1-S	1115		9.0	14.3	31.7	8.3	28.7	6	7.9	0.22	<0.01	0.32	0.16	0.10	240							
-D			8.9		32.6	8.4	29.6	4	8.0	0.22	<0.01	0.02	0.05	0.03								
DR2-S	1133		8.9	18.3	32.1	8.5	29.0	2	8.0	0.22	<0.01	0.06	0.06	0.04	200							
-D			8.9		32.5	8.5	29.6	3	7.9	0.22	<0.01	0.02	0.04	0.03								
DR3-S	1149		8.9	18.0	32.1	8.6	29.2	5	7.9	0.22	<0.01	0.04	0.05	0.04	80							
-D			8.8		32.4	8.6	29.2	3	8.0	0.22	<0.01	0.02	0.06	0.03								
DR4-S	1208		8.8		32.0	8.7	29.0	5	8.0	0.22	<0.01	0.04	0.04	0.04	120							
-D			8.8		32.4	8.9	29.3	3	7.9	0.23	<0.01	0.02	0.04	0.03								
DR5-S	1248		8.9		32.0	9.1	29.0	5	7.9	0.23	<0.01	0.02	0.05	0.04	8[3/]							
-D			8.8		32.5	8.5	29.6	4	7.9	0.23	<0.01	0.02	0.08	0.06								
WTP Eff. 24-hr Comp.[6/]		0.2			3.1		1.9	140	7.4	.15	<.05	15	4.6	3.4	530,000/3,900		200	340	2180	1700	160	24

[1/] Surface sample

[2/] Sample at 10 meters or the bottom

[3/] Estimated count

[4/] Collected at 1435

[5/] Samples collected May 23 from breakwater approximately 30 m and 60 m from discharge site

[5/] Obtained from Heffner (1983)

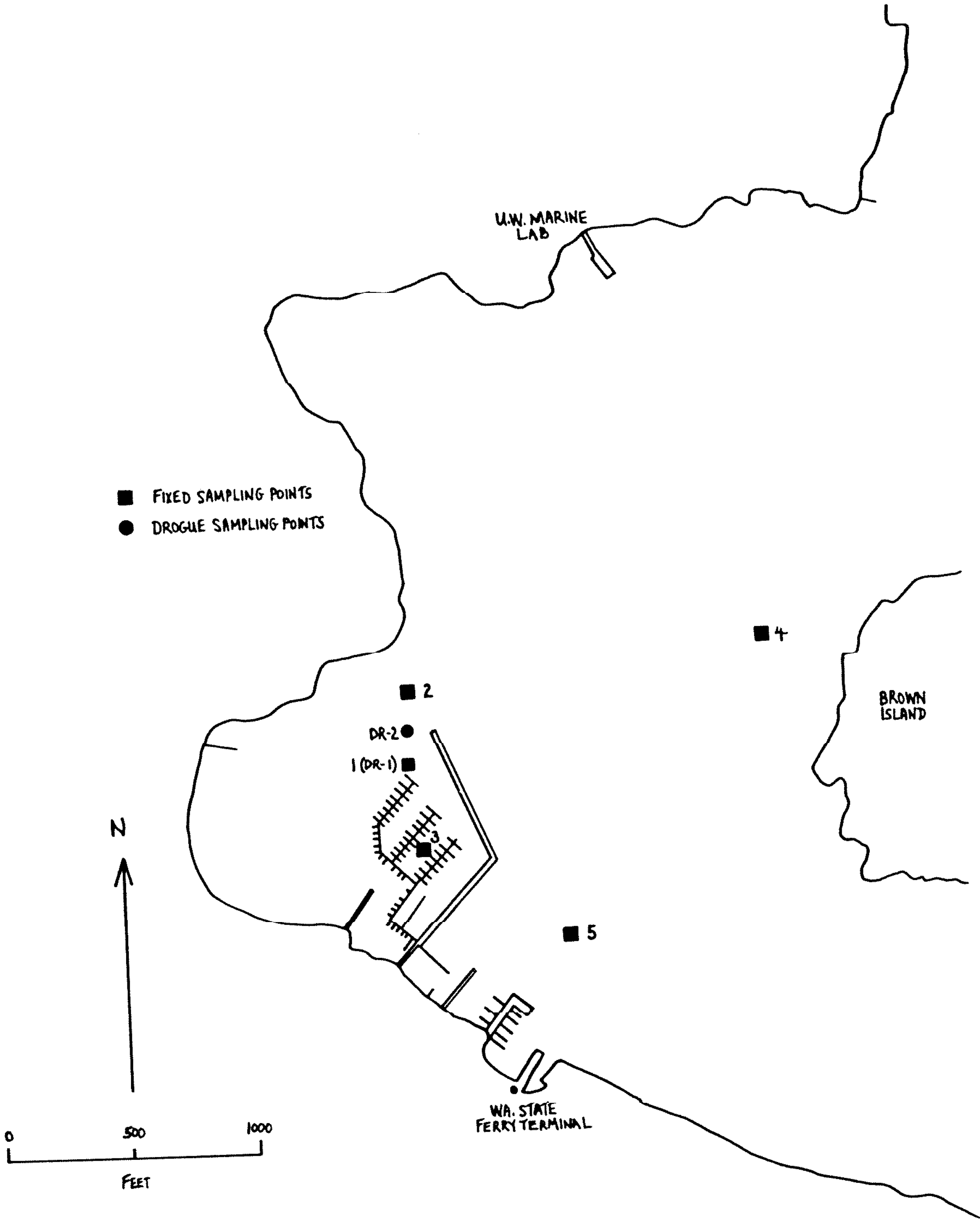

Figure 1. Sampling points in Friday Harbor used by Singleton and Joy (1983). The STP discharge point at the time of the survey was near Station 1.

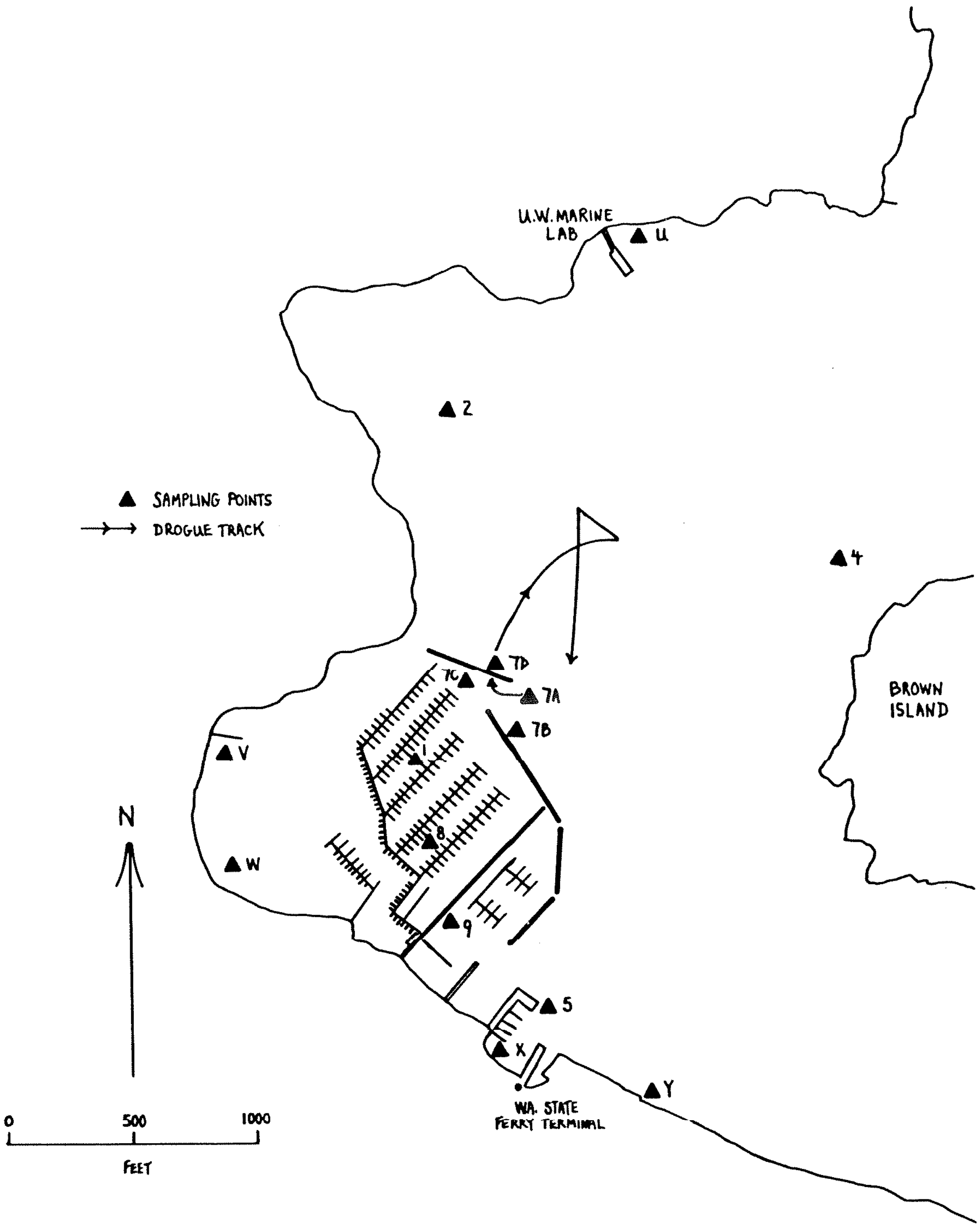

Figure 2. The west end of Friday Harbor showing water sampling points used during a survey conducted on August 13 and 14, 1985. The present STP discharge is located near Station 7A.

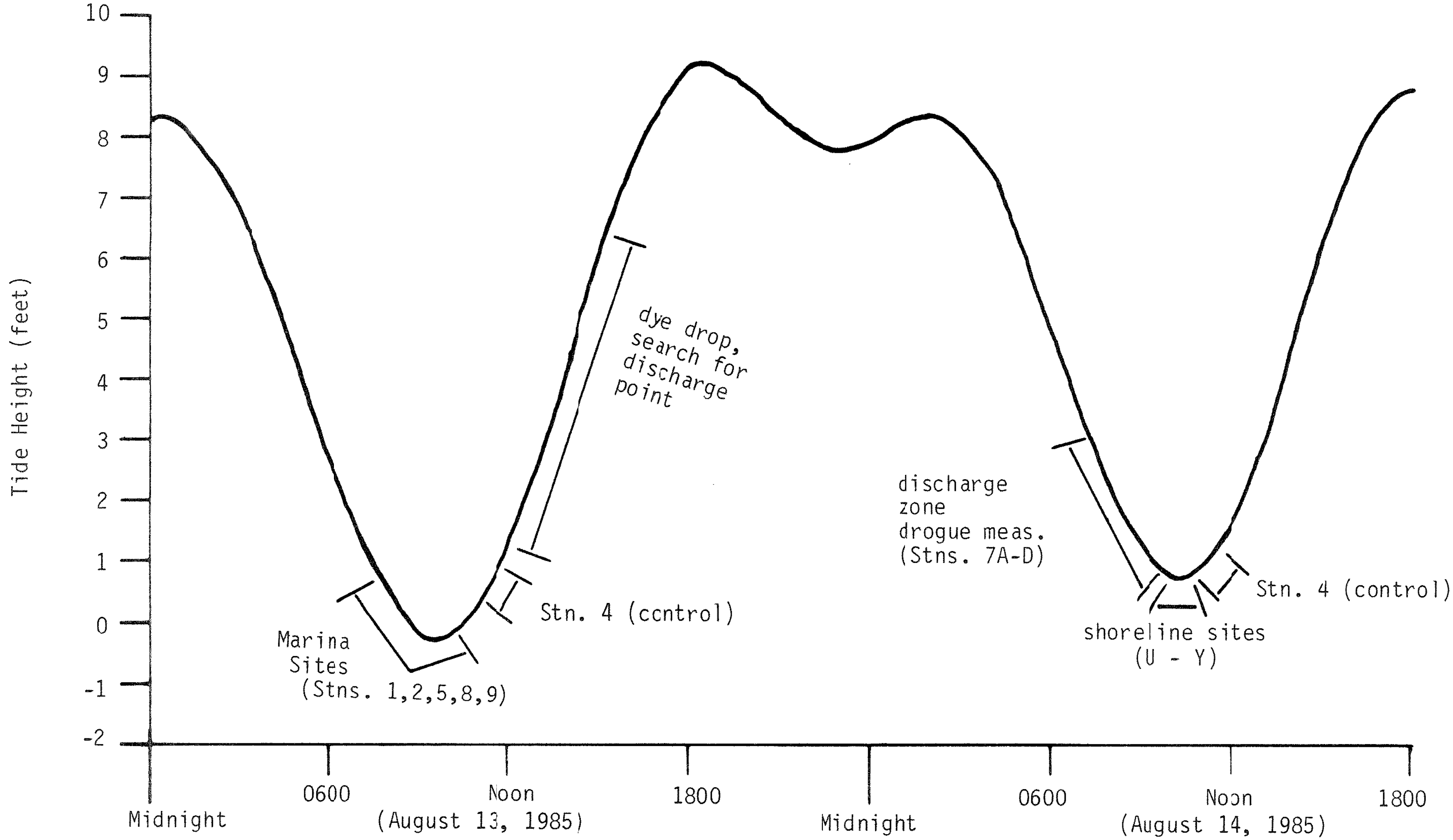

Figure 3. Survey activities and tide heights in Friday Harbor on August 13 and 14, 1985 (MLLW tidal datum; heights corrected from Port Townsend; U.S. Dept. of Commerce, 1985).

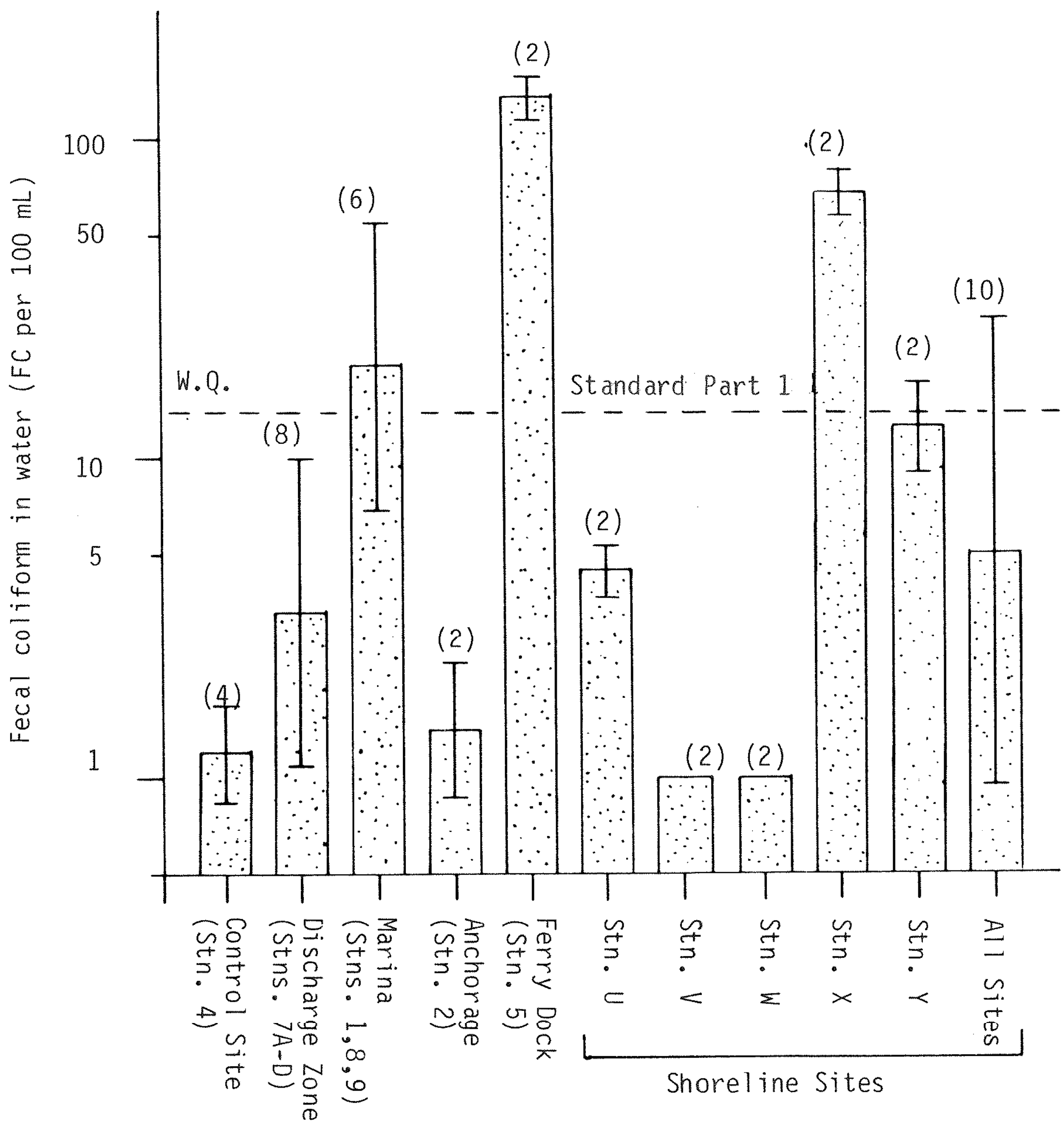

Figure 4. Fecal coliform concentrations at individual sites in Friday Harbor during a water quality survey on August 13-14, 1985. Data are in Appendix B (stippled bars show geometric means. Vertical lines show ± 1 standard deviation of logs. Numbers of data observations are in parentheses).

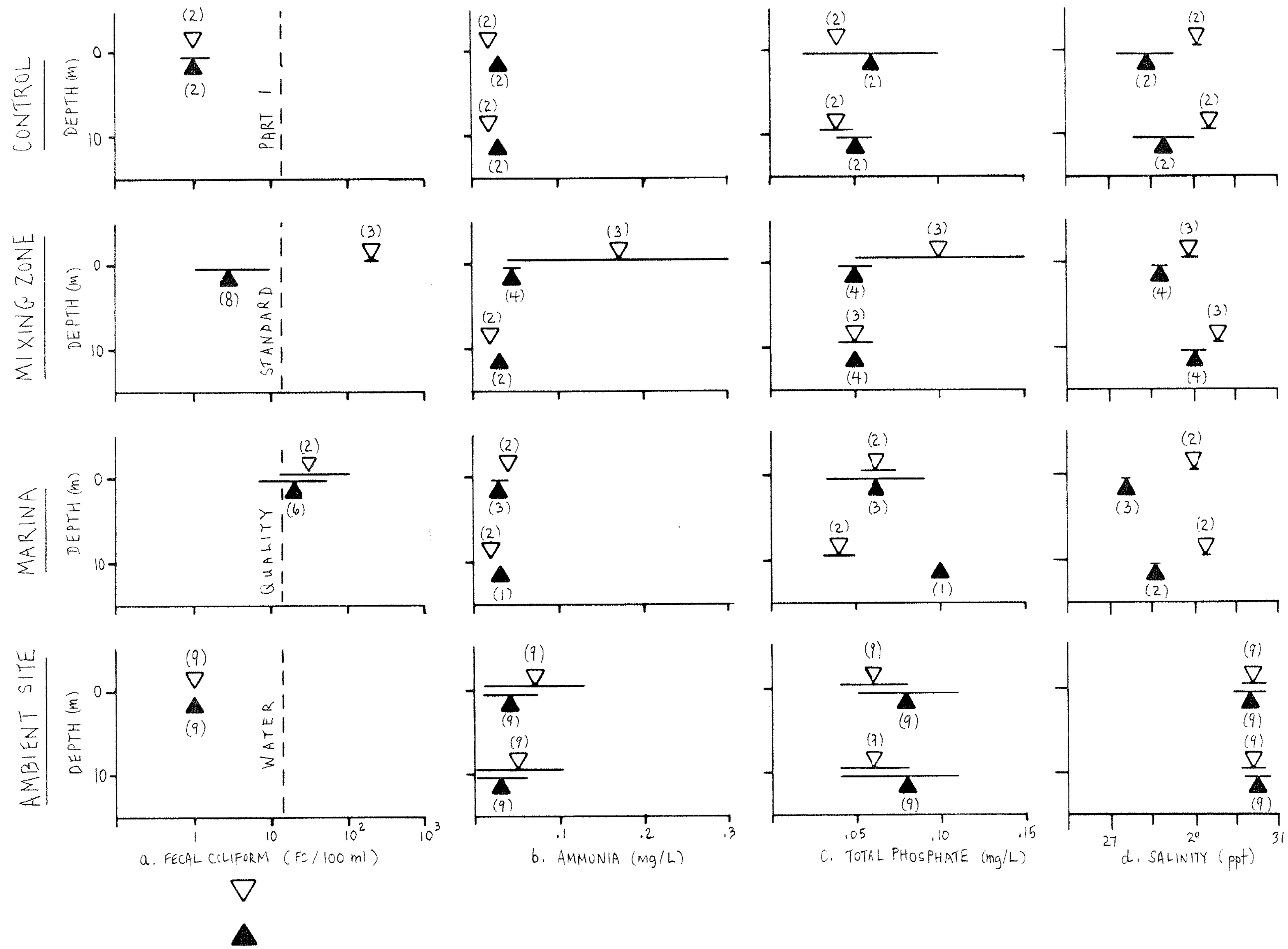

Figure 5. Water quality before (May 1983) and after (August 1985) marina improvements. STP outfall extension and treatment upgrade in several areas in or near Friday Harbor, San Juan Islands (means ± 1 standard deviation, number of data in parentheses). Data are taken from Table 1 (FC) and Appendix B (others).

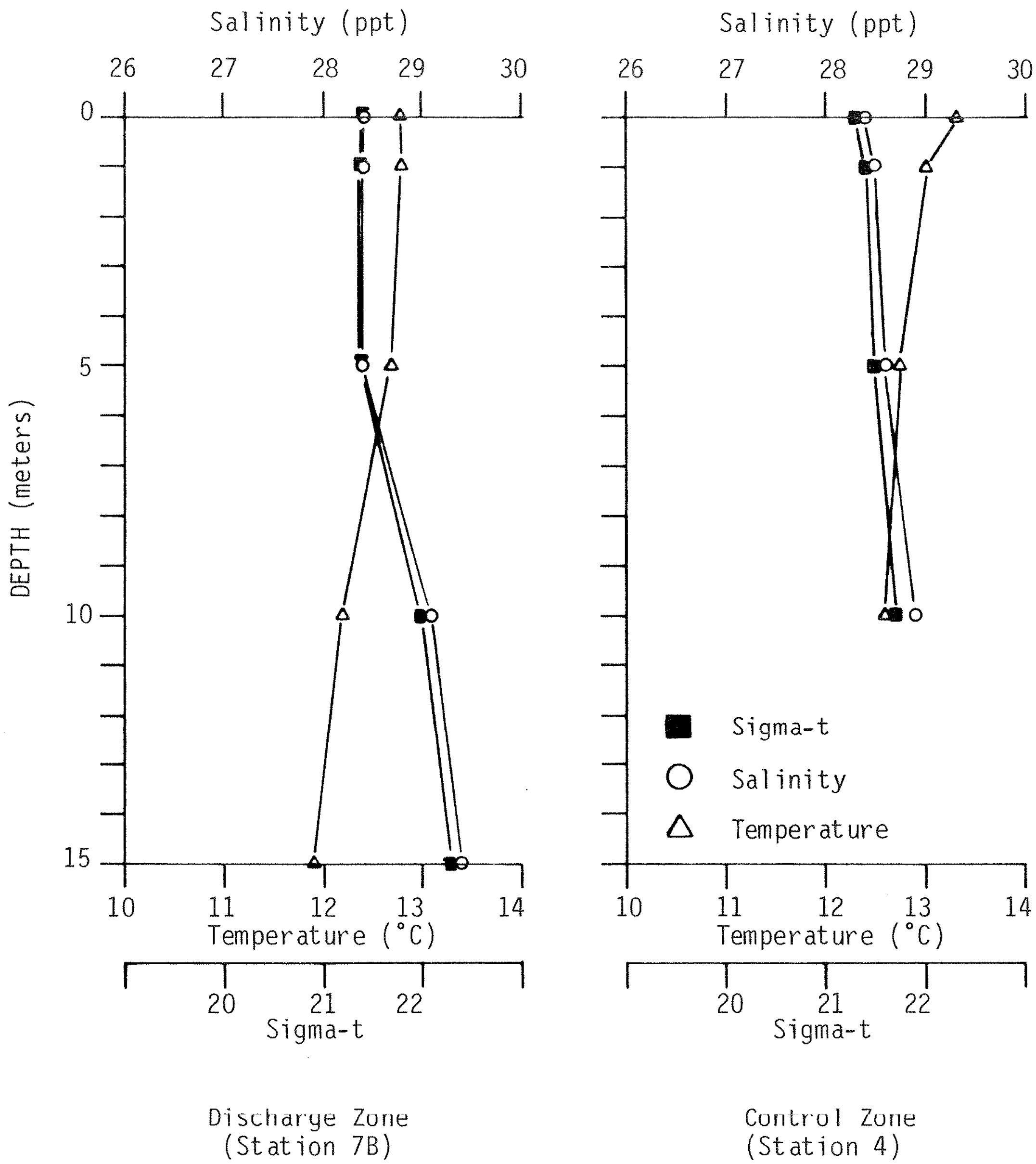

Figure 6. Distribution of temperature, salinity, and density (sigma-t) with depth at two water quality sites in Friday harbor on August 14, 1985.

Appendix C. Results of physical and chemical sampling at Friday Harbor on August 13 and 14, 1985, during a receiving water survey.

Parameter	Depth (m)	Control Site		Mixing Zone Sites				Marina Sites			Other Maritime Sites		STP Effluent
		Stn. 4	Stn. 4	Stn. 7A	Stn. 7B	Stn. 7C	Stn. 7D	Stn. 1	Stn. 8	Stn. 9	Stn. 2	Stn. 5	
Date	--	8/13	8/14	8/14	8/14	8/14	8/14	8/13	8/13	8/13	8/13	8/13	8/14
Time	--	1240	1000	0743	0833	0715	0811	0825	0842	0745	0903	0803	
Depth (m)	--	11.0	12.0	17.0	16.0	17.0	17.0	10.0	4.5	6.5	10.5	7.0	
Temp (°C)	0	13.9	13.3	12.8	12.8	12.8	12.8	13.4	13.4	13.5	13.6	13.4	19.6
	1	13.8	13.0	12.8	12.8	12.8	12.8	13.3	13.3	13.5	13.4	13.4	
	3	13.7	--	--	--	--	--	13.3	13.3	13.2	13.3	13.3	
	5	13.6	12.7	12.8	12.7	12.7	12.8	13.2	--	13.1	13.2	13.0	
	10	13.3	12.6	12.4	12.2	12.7	12.4	12.9	--	--	13.0	--	
	15	--	--	12.2	11.9	12.1	11.5	--	--	--	--	--	
Salinity (o/oo)	0	27.4	28.4	27.9	28.4	28.2	28.2	27.3	27.5	27.4	27.2	27.1	1500[a]
	1	27.4	28.5	28.3	28.4	28.2	28.6	27.4	27.5	27.3	27.3	27.4	
	3	27.4	--	--	--	--	--	27.6	27.6	27.5	27.6	27.6	
	5	27.5	28.6	28.6	28.4	28.4	28.4	27.7	--	28.0	27.8	27.9	
	10	27.8	28.8	28.9	29.1	28.5	29.3	28.2	--	--	28.1	--	
	15	--	--	29.2	29.4	29.5	29.8	--	--	--	--	--	
Sigma-t (g/cm^3)	0	20.4	21.3	21.0	21.4	21.2	21.2	20.4	20.6	20.5	20.3	20.2	
	1	20.4	21.4	21.3	21.4	21.2	21.5	20.5	20.6	20.4	20.4	20.5	
	3	20.4	--	--	--	--	--	20.7	20.7	20.6	20.7	20.7	
	5	20.5	21.5	21.5	21.4	21.4	21.4	20.7	--	21.0	20.8	20.9	
	10	20.8	21.7	21.8	22.0	21.5	22.1	21.2	--	--	21.1	--	
	15	--	--	22.1	22.3	22.3	22.7	--	--	--	--	--	
Dissolved Oxygen (mg/L)	0	7.8	7.4	7.2	7.2	7.5	7.4	7.7	7.7	7.7	7.8	7.6	56[b]
	1	7.6	7.2	7.2	7.1	7.5	7.2	7.5	7.6	7.7	7.6	7.5	250[c]
	3	7.5	--	--	--	--	--	7.5	7.5	7.5	7.5	7.5	
	5	7.5	7.1	7.1	7.1	7.2	7.2	7.4	--	7.1	7.4	7.2	
	10	7.4	6.9	6.8	6.7	7.1	6.9	7.1	--	--	7.2	--	
	15	--	--	6.7	6.4	6.5	6.1	--	--	--	--	--	
Dissolved Oxygen (% sat.)	0	88	84	80	80	84	83	86	86	87	88	85	--
	1	86	81	80	79	84	80	84	85	87	85	84	
	3	85	--					84	84	84	84	84	
	5	85	79	79	79	80	80	83	--	80	83	80	
	10	83	77	76	74	79	77	79	--	--	81	--	
	15	--	--	74	71	72	67	--	--	--	--	--	
NO_3-N (mg/L)	0	0.15	0.18	0.18	0.18	0.17	0.18	0.15	0.14	0.14	0.40	0.14	--
	5	--	0.19	0.18	0.18	0.18	0.18	--	0.16	0.17	--	0.16	
	10	0.17	0.21	0.18	0.21	0.19	0.20	0.18	--	--	0.16	--	
	15	--	--	0.21	-.24	0.20	0.20	--	--	--	--	--	
	17	--	--	0.21	--	0.21	0.20	--	--	--	--	--	
NO_2-N (mg/L)	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	--
	5	--	<0.01	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01	--	<0.01	
	10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	--	--	<0.01	--	
	15	--	--	<0.01	<0.01	<0.01	<0.01	--	--	--	--	--	
	17	--	--	<0.01	--	<0.01	<0.01	--	--	--	--	--	
NH_3-N (mg/L)	0	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	--
	5	--	0.03	0.03	0.02	0.03	0.03	--	0.03	0.03	--	0.03	
	10	0.03	0.03	0.03	0.03	0.02	0.03	0.03	--	--	0.03	--	
	15	--	--	0.04	0.04	0.04	0.03	--	--	--	--	--	
	17	--	--	0.04	--	0.04	0.03	--	--	--	--	--	
O-PO_4-P (mg/L)	0	0.02	0.03	*	*	0.02	0.04	0.06	0.04	0.05	0.04	0.04	--
	5	--	0.04	*	0.02	0.02	0.05	--	0.04	0.03	--	*	
	10	0.05	*	*	0.05	0.03	0.05	0.05	--	--	0.05	--	
	15	--	--	*	0.02	0.02	0.02	--	--	--	--	--	
	17	--	--	0.05	--	0.02	0.05	--	--	--	--	--	
T-PO_4-P (mg/L)	0	0.09	0.04	0.05	0.05	0.06	0.04	0.10	0.04	0.05	0.10	0.05	--
	5	--	0.05	0.05	0.05	0.05	0.05	--	0.05	0.04	--	0.04	
	10	0.06	0.04	0.05	0.05	0.06	0.05	0.10	--	--	0.09	--	
	15	--	--	0.05	0.06	0.06	0.05	--	--	--	--	--	
	17	--	--	0.06	--	0.06	0.05	--	--	--	--	--	
pH (S.U.)	0	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.8	7.7	7.8	7.8	7.0
	1	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	
	3	7.9	--	--	--	--	--	7.8	7.8	7.8	7.8	7.8	
	5	7.9	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.7	7.8	7.8	
	10	7.9	7.8	7.8	7.8	7.8	7.8	7.8	--	--	7.8	--	
	15	--	--	7.8	7.8	7.8	7.7	--	--	--	--	--	
Turbidity (NTU)	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	36
	5	--	1	<1	<1	<1	<1	--	<1	<1	--	<1	
	10	<1	<1	1	<1	<1	<1	1	--	--	<1	--	
	15	--	--	<1	2	<1	<1	--	--	--	--	--	
	17	--	--	1	--	2	<1	--	--	--	--	--	
Secchi (m)	--	7.0	8.0	8.0	--	7.5	--	7.5	bottom	bottom	--	bottom	
Flow (MGD)	--	--	--	--	--	--	--	--	--	--	--	--	0.19
Cond. (umhos/cm)	--	--	--	--	--	--	--	--	--	--	--	--	1720
Cl_2 Res. (mg/L)	--	--	--	--	--	--	--	--	--	--	--	--	1.1
TSS (mg/L)	--	--	--	--	--	--	--	--	--	--	--	--	41

[a]mg/L total solids [b]mg/L BOD [c]mg/L COD *laboratory error