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DEPARTMENT OF ECOLOGY

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MEMORANDUM
May 11, 1981

To: Jim Krull

From: Tim Determan

Subject: The Environmental Effects of Water Pollution Associated with the Salmon Beach Community on Tacoma Narrows Waters

INTRODUCTION

During October and November 1980 and January 1981, the Marine Unit of the Water and Wastewater Monitoring Section, Department of Ecology (DOE), performed a water quality survey of the Tacoma Narrows, Salmon Beach, in Pierce County. The purpose was to evaluate the extent of fecal coliform pollution associated with wastewaters discharged from homes located along Salmon Beach.

Salmon Beach consists of about 80 single-family residences, most of which are built on pilings over the intertidal zone. The community stretches for about 3,700 feet (1,200 m) along a narrow coastal bench located below a steep escarpment on the east side of the Tacoma Narrows, two miles (3.2 km) north of the Tacoma Narrows Bridge (Figure 1). Salmon Beach has evolved from a turn-of-the-century fishing village to its present form. A few structures are original, but most have been extensively remodeled and some are entirely new. The community has access to potable water and power and most residences have toilets, sinks, showers, and washing machines. All forms of household wastewater are discharged directly onto the upper intertidal zone or into the water, depending on tide height.

The beach north of Salmon Beach is part of Point Defiance Park. No structures exist along this section of beach and according to Ken Heany of the Tacoma Metropolitan Parks Department, this area receives minimal use because of limited accessibility. Activities include occasional beachcombing and hiking. However, fishing from shore or small craft is quite popular farther north near Point Defiance. During the reconnaissance performed in September 1980 as part of this survey, 40 to 50 boats were seen near Point Defiance and 8 to 10 beach walkers were observed on Owen Beach to the east of Point Defiance. None were observed to the south.

Tidal current characteristics for the Tacoma Narrows region have been summarized by NOAA (1973). Data are displayed along two cross-channel transects. The northern transect is near Point Defiance and the southern one is due east of Point Evans. Salmon Beach is located between them. No specific data are shown for Salmon Beach. Tidal currents north of Salmon Beach show a consistent NNW set regardless of tide stage, while the currents to the south are shown to reverse from northerly to southerly during early rising tide. These data suggest a node or eddy in the vicinity of Salmon Beach with possible upwelling occurring.

Fecal Coliform in Marine Waters

The Tacoma Narrows is classified as Class AA (extraordinary) (DOE, 1979). Beneficial uses to be protected by this classification include swimming, aesthetics, boating, and fisheries such as commercial and sport salmon, other food fish, and shellfish rearing and harvesting. The fecal coliform criterion applicable to these waters is as follows: "Fecal coliform organisms shall not exceed a median value of 14 organisms per 100 ml, with not more than 10 percent of samples exceeding 43 organisms per 100 ml." This standard is quite strict because of the ability of shellfish to concentrate fecal coliforms and other bacterial pathogens and viruses found in water and sediments.

Coliform bacteria have long been used as a primary indicator of a water's sanitary quality because of their association with soils and feces of warmblooded animals (EPA, 1976). Fecal coliform bacteria have proven to be more useful than total coliforms because fecal coliforms are restricted to the intestinal tract of warmblooded animals. Other organisms and types of organisms have been proposed as indicators of fecal pollution; however, costs of analyses and lack of a strict correlation between numbers of organisms and pollution, other than fecal, limit their applicability (EPA, 1976).

Fecal coliforms are, therefore, used as a microbial indicator of the presence of human or animal wastes in water. The maximum levels permitted in water were established to minimize the risk of contact with pathogenic organisms that might be associated with such wastes. The relationship between the numbers of specific disease-causing organisms in water and the likelihood of disease outbreak is complex since the likelihood depends on the disease organism, the condition of the host community, and a variety of environmental factors. However a multitude of studies have shown that the greater the fecal coliform level in water, the greater the incidence of water-borne diseases in human populations.

Fecal Coliforms in Shellfish

Vasconcelos, *et al.*, (1969) studied bacteria accumulation-elimination responses of Pacific oysters (*Crassostrea gigas*) and Manila clams (*Tapes semidecussata*) in Pacific Northwest marine waters. They conducted eight experiments over one year. Figure 2 compares the mean and range of fecal coliform densities in Manila clams and seawater during their study. Temperature and rainfall data during each experiment also are shown. Temperatures are "means" estimated as the average of the lowest and highest values reported during each experiment by Vasconcelos, *et al.*, (Table 1).

Theoretically, rainfall should positively correlate with terrestrial runoff and levels of fecal coliforms in receiving waters. Further, temperature should positively correlate with metabolic activity which is related to filtration rate and thus to levels of fecal coliforms in shellfish tissue. In order to evaluate the strength of these assumed correlations, an analysis was performed (Sokal and Rohlf, 1969) using fecal coliform data in water and shellfish normalized with the Log-10 transformation. Correlation between rainfall and fecal coliform levels in seawater was moderate ($r = 0{\cdot}66$; $n = 8$) and correlation between temperature and coliform in tissue was somewhat higher ($r = 0{\cdot}84$; $n = 8$). The best correlation was between fecal coliform levels in clams and seawater ($r = 0{\cdot}94$; $n = 8$).

Table 1 shows accumulation ratios for Manila clams and Pacific oysters together with rainfall and temperature. The accumulation ratio is a value determined by division of the fecal coliform density in shellfish (FC per 100 gr) by the fecal coliform density in surrounding waters (FC per 100 ml). In all experiments, the clams accumulated higher levels of fecal coliform than did the oysters. The ratios do not show clear seasonal effects. However, the ratios are useful for establishing a range that we might reasonably expect during the year. The annual mean ratio for Manila clams was 52.2 and 20.8 for oysters.

The National Shellfish Sanitation Program (HEW, 1965) recommends fecal coliform densities not exceed 230 MPN per 100 gr of tissue to be marketable. Fecal coliform densities exceeding this value are subject to market rejection. The Washington State Department of Social and Health Services (DSHS) shellfish sanitation program applies these standards to commercial harvesters and public shellfish collection areas throughout the state.

Sampling Strategy

It is logical to assume that the greatest probability of marine water contamination off Salmon Beach occurs during rising tide when wastes deposited during low tide are entrained by the incoming water. We would expect short-term, high-level contamination during incoming tide with less contamination anticipated at other times. Maximum contamination would be expected during rising tides that immediately follow intensive use of sewage facilities such as early morning or evening. Water sampling was conducted during these conditions.

The survey included three parts. For each part, a basic set of eight fixed stations was sampled to provide a statistical basis for comparisions later (Figure 1). Part I (Time-series Sampling) was performed at Salmon Beach fixed stations. For Part II, fixed-station samples were supplemented with a dynamic flow study whereby Rhodamine WT dye was dropped at the south end of Salmon Beach and the movement monitored. Water quality samples were collected periodically during this effort. Part III involved collecting shellfish (mussels) for tissue analysis (bacteriological) at three locations. These data were compared with the National Shellfish Standards (HEW, 1965).

The methods and results for the three parts of the study are outlined in the text that follows.

PART I: TIME-SERIES STUDY

Methods

Sampling was conducted at mid-morning (0730-0900) on October 29, 1980 to monitor changes in contaminant levels at the fixed stations over time. As previously stated, a reconnaissance survey indicated long-shore currents flow NNW all along Salmon Beach. Fixed Stations 2, 3, and 4 were sampled at the surface at half-hour intervals as the tidal waters encroached the upper intertidal zone. Surface samples were collected at other fixed stations as time permitted during the study. Parametric coverage at all stations included fecal coliforms, nutrients (NO_3-N, NO_2-N, NH_3-N, O-PO_4-P), and total suspended solids. All laboratory analyses were conducted by the Department of Ecology using standard procedures (EPA, 1979). In addition, samples were taken for methylene-blue active substances (MBAS) and analyzed during a Hach Model DE-2 detergents test kit.

Results

The results of the sampling performed at the Salmon Beach Stations 2, 3, and 4 are shown in Figure 3. Bacterial counts at Station 2 (upstream) were near zero for the duration of the study, reflecting background conditions which would be expected for Puget Sound waters in general. Fecal coliform densities at Station 3 (mid-community), however, increased geometrically and reached a maximum of 1,000 organisms per 100 ml by the end of the 1-1/2 hour sampling period. A steady-state plateau which would be expected if fecal coliform accumulation was balanced by dilution and turbulent mixing was not evident. On the other hand, at

Station 4 (the "downstream" end of the community), fecal coliform densities quickly peaked at 100 organisms per 100 ml, then remained constant during the remainder of the study, suggesting steady-state fecal coliform input and diluting processes. This plateau value was seven times greater than the median value of 14 FC per 100 ml allowed by the Water Quality Standards.

PART II: DYE STUDY

Methods

On November 17, 1980, a dynamic flow study was conducted during circumstances comparable to those of Part I. As before, current direction was consistently toward NNW. Rhodamine WT dye was used to tag a water mass at the upstream end (SSE) of the community. Surface samples for fecal coliform and nutrients were collected immediately ahead of the dye cloud as it was transported along the shoreline, about 15 feet from the water's edge. Samples were taken at 10-to-15-minute intervals. The dye cloud was reinforced with additional inoculations five times during the study. Depending on the downstream trend shown in sample results, rates of change in bacteria levels could theoretically be identified and measured as the cloud drifted past the community toward Point Defiance, and an affected area could be approximated. Two replicate samples were taken in order to evaluate field variability. In addition, the fixed stations were sampled. Means ± 1 standard deviation were determined from Log-10 transformed data and graphed following conversion back to linear values.

Results

The total time of passage of the dye cloud was about 1.5 hours at an average velocity of 34 feet (11 m) per minute. These data are generally much more variable than in Part I, and the cumulative process suggested in Part I was not apparent. Initial sampling of the dye-tagged mass of water showed no fecal coliform contamination upstream of the community at Point A. A density of 980 fecal coliform per 100 ml was reached within the first 10 minutes of drift along the community (Point B). During the next 60 minutes, fecal coliform densities remained relatively high, but dropped sharply by mid-community (Point F) and remained at elevated levels along the north half of Salmon Beach. Coliform levels then dropped to acceptable limits as the water mass moved farther north toward Point Defiance.

PART III: SHELLFISH TISSUE SAMPLING

Methods

In addition to the two water quality sampling programs, concentrations of fecal coliform in tissue of shellfish were measured at selected sites. *Mytilus edulis*, the common mussel, was selected as the test organism because it is a common upper and mid-intertidal resident of most rocky shores in Tacoma Narrows.

On January 9, 1981 mussel specimens were collected at three Tacoma Narrows sites: Station 2 (near the center of Salmon Beach); Station 7 (S.E. bridge support of Narrows Bridge, near Tacoma STP discharge); and Station 8 (Point Evans control station). The mussels were detached from rocks and placed intact in plastic sterilized bags, iced, and taken to the Department of Ecology laboratory. A subset of 15 specimens from each sample was cleaned, scraped, and rinsed in distilled water. Each organism was removed from its shell with a sterilized knife. Organisms found to have open shells were discarded. A homogenate was prepared and Most Probable Number (MPN) analysis performed according to the methods found in APHA (1970).

Results

The results of shellfish samples taken near Point Evans, Tacoma STP, and Salmon Beach are included in Figure 5. The results suggest strong positive correlation with fecal coliform levels in water samples during the study period. The shellfish sample from Point Evans showed densities equal to the state shellfish standard. The sample from the Narrows Bridge footing (Station 7) exceeded the standard by about 50 percent. The sample taken in the center of Salmon Beach showed fecal coliform densities 5,000 percent or 50 times higher than the state standard. It was possible to take only one sample at each site due to laboratory load limitations. However, the results are very strong evidence that wastewater disposal practices at Salmon Beach are the cause of fecal pollution of nearby Tacoma Narrows waters.

DISCUSSION

The results obtained during Parts I and II of this study show substantially lower bacteria densities at the northern end of Salmon Beach than mid-community. These results may be attributed, on one hand, to increased tidally-induced mixing processes and on the other hand, by removal of wastes prior to our sample collection. It is tempting to conclude that lower fecal coliform densities at the north end relative to mid-community are characteristic and predictable since results from both studies suggest this. However, both survey designs may contain time artifacts. Generally, the houses at the northern end of the community extend further seaward because of the narrowness of the coastal bench compared to the south. Thus, in the north, household wastes may be deposited lower on the intertidal beach and become entrained earlier in the rising tide. During Part I, we may have started our time-series sampling after entrainment was well underway at the north station. During Part II, northern samples were taken much later than southern samples. This may account for the lower results in the north.

Figure 5 summarizes pooled fecal coliform data collected at fixed stations at several areas in Tacoma Narrows during all parts of this study. These data were transformed and statistics prepared as discussed previously. These data do not include samples taken at intermediate points during Part II. Only samples collected close to the fixed stations were included. It should be noted that the lower end of the standard deviation bars are truncated at 1 fecal coliform per 100 ml for Point Evans (control), Tacoma STP, and Station 2 ("upstream" from Salmon Beach). This is indicative of a skewed non-normal distribution probably due to the presence of a number of zeros in the data for the first three ranked stations. The means for Stations 2, 6, 7, and 8 appear to be nearly equal with comparable variance, suggesting strongly that no significant difference exists. Also, the Point Defiance (Station 1) and Gold Creek (Station 5) means appear to be rather close and both are within the state standard. However, several of the Gold Creek values and one Point Defiance value are higher than the state standard. The Salmon Beach community mean is well above the others. However, the Salmon Beach data are highly variable and a number of values overlap values from Gold Creek and Point Defiance. A visual comparison of means among the six areas would suggest that "downstream" Salmon Beach combined results are clearly higher than the station "upstream" from Salmon Beach community, Tacoma STP stations, or the control station at Point Evans.

The conclusion for the case of Salmon Beach versus Point Defiance and Gold Creek is less straight-forward. In order to compare those means, the Student-Newman-Keuls test for unequal sample sizes was applied to the data (Sokal and Rohlf, 1969). This test is appropriate for after-the-fact multiple comparision of means. Normalized (log-10) data were ranked in a two-way matrix, and the differences between each pair determined. Each difference was compared with a calculated least-significant range (LSR) for each pair of samples. The observed difference between each pair of means was then compared with the LSR. If the LSR was less than each observed difference, the difference was considered significant. If the LSR was the greater, nonsignificance was the result. The conclusions are shown in Table 2. The "downstream" Salmon Beach stations (Rank 6) mean was significantly different from all other stations. Point Evans, Tacoma STP discharge zone, and "upstream" Salmon Beach sites showed no significant differences. The Gold Creek mean was not significantly different from Point Defiance, although Gold Creek was significantly different from Salmon Beach ("upstream") and Tacoma STP discharge zone. The test resulted in one apparent ambiguity, however. Gold Creek values were not shown to be significantly different from those at Point Evans. This is unlikely since Point Evans means and variance is less than Tacoma STP zone or "upstream" Salmon Beach means. This result may be due to the skewed nature of the data at the three areas with the lowest values.

Table 3 summarizes all of the water quality sampling data collected in Tacoma Narrows during the survey. The high level of mixing and dilution energy in the Tacoma Narrows accounted for the low levels of ammonia in the waters near the Tacoma STP and the Salmon Beach community. Ammonia levels at all stations were at or near the detection limit. This also was the case with nitrite and total suspended solids. Further, there appeared to be no significant difference among stations for either nitrate or phosphate. The same was true of dissolved oxygen levels at all stations except Gold Creek. Gold Creek oxygen levels probably are elevated by aeration while flowing down over boulders into Tacoma Narrows. MBAS levels were zero in all samples except for a trace amount in one out of six Salmon Beach samples taken during Part II. In summary, these data provide no evidence that the Salmon Beach activities cause any detectable differences in water quality as measured by the physical/chemical parameters. Fecal coliform values only are different among stations. Other issues such as Salmon Beach as a source of toxic substances were not the subject of this study and no conclusions can be drawn.

SUMMARY

This study addressed the question of the role that the Salmon Beach community plays in water quality in the Tacoma Narrows.

Statistical analyses of fecal coliform data from several sources and other locations showed the mean value at Salmon Beach to be higher and significantly different from any other area sampled. The mean value at Point Defiance was found to be equal to the discharge from Gold Creek, a small stream discharging into Tacoma Narrows. The observation of a consistent northward current during rising tides and the apparent absence of any significant discharge between Salmon Beach and Point Defiance are evidence that Salmon Beach wastewaters contribute to elevated fecal coliform levels as far north as Point Defiance. Although these values generally were found to be within levels allowable under the state water quality standards during this survey, there is evidence that the affected zone may extend 2,000 feet (650 m) NNW along the beach. The extent of this zone is variable in time, depending on tidal current velocities and the total volume of waste discharged.

Several studies were conducted at Salmon Beach to characterize the mechanism of entrainment of household wastewater as the tide rises and

how values for fecal coliform change over time and space. The time-series study showed continually rising values at a fixed station near mid-community, while a maximum contaminant level was reached "downstream" of the Salmon Beach. The flow study showed elevated levels of fecal coliform on the south end of the community which dropped to much lower values downstream in the north half of the community. The apparent lower levels in the north half of the community may be due to time artifacts in the study design or a greater degree of turbulent mixing processes. In either case, the maximum FC density reached in Salmon Beach was nearly 1,000 fecal coliform per 100 ml. The geometric mean of all values was 43 fecal coliform per 100 ml, well in excess of the state water quality standard.

Shellfish samples provided additional evidence that Salmon Beach contributes a significant level of fecal coliform to Tacoma Narrows waters. Levels of fecal coliform in mussel tissue from the Salmon Beach intertidal zone were 50 times higher than at Point Evans or the Tacoma STP discharge zone. Levels of FC in mussel tissue were strongly correlated with FC levels in surrounding waters.

Although the waste discharges of Salmon Beach are the most significant source of fecal pollution to adjacent waters of Tacoma Narrows north of the suspension bridge, there is no evidence to suggest that these discharges affect water quality in any other way.

CONCLUSIONS

1. Fecal coliform levels in water and shellfish at Salmon Beach were shown to be significantly higher than any other source in the Tacoma Narrows. These levels were due to discharges from individual residences within the community.

2. On a rising tide, the longshore current carried Salmon Beach wastewaters northward toward Point Defiance. The affected zone extended 2000 feet (650 m) along the beach.

3. Although the waste discharges at Salmon Beach are the most significant source of fecal pollution to Tacoma Narrows waters, they do not appear to affect water quality in any other way.

ACKNOWLEDGMENTS

The author wishes to thank the residents of Salmon Beach for their understanding and cooperation in the completion of this study, especially considering the sensitivity of the discussion and the inconvenient times during which our surveys were conducted. Special gratitude

Memo to Jim Krull
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May 11, 1981

is extended to Kelley Reynolds, President of the Salmon Beach Association and the several Salmon Beach citizens who accompanied us, observed our field methods, and provided us with information and suggestions.

TAD:cp

Attachments

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Table 1. Accumulation ratios of Pacific oysters and Manila clams. (from Vasconcelos, *et al.*, 1969)

Date (Month)	Temperature Mean	(°C)	Total Precipitation[a] (inches)	Accumulation Ratio [FC] in shellfish/[FC] in water Clams	Oysters
Nov. 1965	9.65	8.7 - 10.6	7.57	44	13
Jan. 1966	7.60	7.3 - 7.9	10.61	18	4
Feb. 1966	7.50	7.0 - 8.0	2.97	63	24
Mar. 1966	6.50	4.0 - 9.0	8.38	132	88
July 1966	19.00	15.0 - 23.1	0.88	49	13
Aug. 1966	19.80	16.7 - 22.8	0.35	52	12
Oct. 1966	10.00	8.6 - 11.5	3.65	27	6
Nov. 1966	10.30	9.8 - 10.8	7.35	35	6

[a]Obtained from climatological data -- U.S. Department of Commerce

Table 2. Comparison among means of fecal coliform data collected at Tacoma Narrows fixed sta
Student-Newman-Keuls test (Sokal and Rohlf, 1969).

			Rank	1	2	3	4
			Mean (Y)	.050	.108	.143	.772
			No. of Data (n)	6	10	7	5
Rank[1/]	Location	Mean (Y)	No. of Data (n)	Difference between means: (row mean-colum Calculated LSR			
1	Point Evans (Control, Station 8)	.050	6	X			
2	Tacoma STP discharge zone (Stations 6, 7)	.108	10	.058 / .603(ns)	X		
3	Salmon Beach ("upstream" Station 2)	.143	7	.093 / .760(ns)	.035 / .570(ns)	X	
4	Point Defiance (Station 1)	.772	5	.722 / .930(ns)	.664 / .760(ns)	.629 / .670(ns)	X
5	Gold Creek (Station 5)	.996	5	.946 / .988(ns)	.888 / .840*	.853 / .800*	.224 / .730(n
6	Salmon Beach (Stations 3, 4)	1.653	15	1.603 / .820*	1.545 / .940*	1.510 / .690*	.881 / .730*

1/ Data are ranked from lowest to highest mean FC densities.
* = Difference between means found to be significant at P = 0.05.
ns = Difference between means found to be not significant at P = 0.05.

Table 3. Summary of environmental data from all areas in the Tacoma Narrows.

Stations	Fecal Coliform (FC/100 ml)			NO_3-N[3]	NO_2-N[3]	NH_3-N[3]	O-PO_4-P[3]	TS
	G.M.(n)[1]	Median	% Excess[2]	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(m
Point Evans (Station 8 - Control)	1 (6)	1	0	.35 ± .01 (4)	<.01 (4)	.01 ± .00 (4)	.06 ± .01 (4)	10 ±
Tacoma STP (Stations 6,7)	1 (10)	1	0	.36 ± .01 (4)	<.01 (4)	.01 ± .00 (4)	.06 ± .01 (4)	6 ±
Salmon Beach Upstream (Station 2)	1	1	0	.35 ± .01 (6)	<.01 (6)	<.01 (6)	.06 ± .01 (6)	5 ±
Pt. Defiance (Station 1)	6 (5)	8	0	.34 ± .02 (4)	<.01 (4)	.02 ± .01 (4)	.05 ± .01 (4)	7 ±
Gold Creek[4] (Station 5)	10 (5)	13	20	.31 ± .04 (4)	<.01 (4)	.01 ± .00 (4)	.06 ± .01 (4)	6 ±
Salmon Beach[4] (Stations 3,4)	44	30	47	.35 ± .01 (34)	<.01 (34)	.01 ± .00 (34)	.06 ± .01 (34)	5 ±

1/ Number of data.

2/ Percentage of samples exceeding water quality standards for fecal coliform (DOE, 1979).

3/ Data are shown as means ± 1 standard deviation. Numbers of data are in parentheses.

4/ This station violated water quality standards.

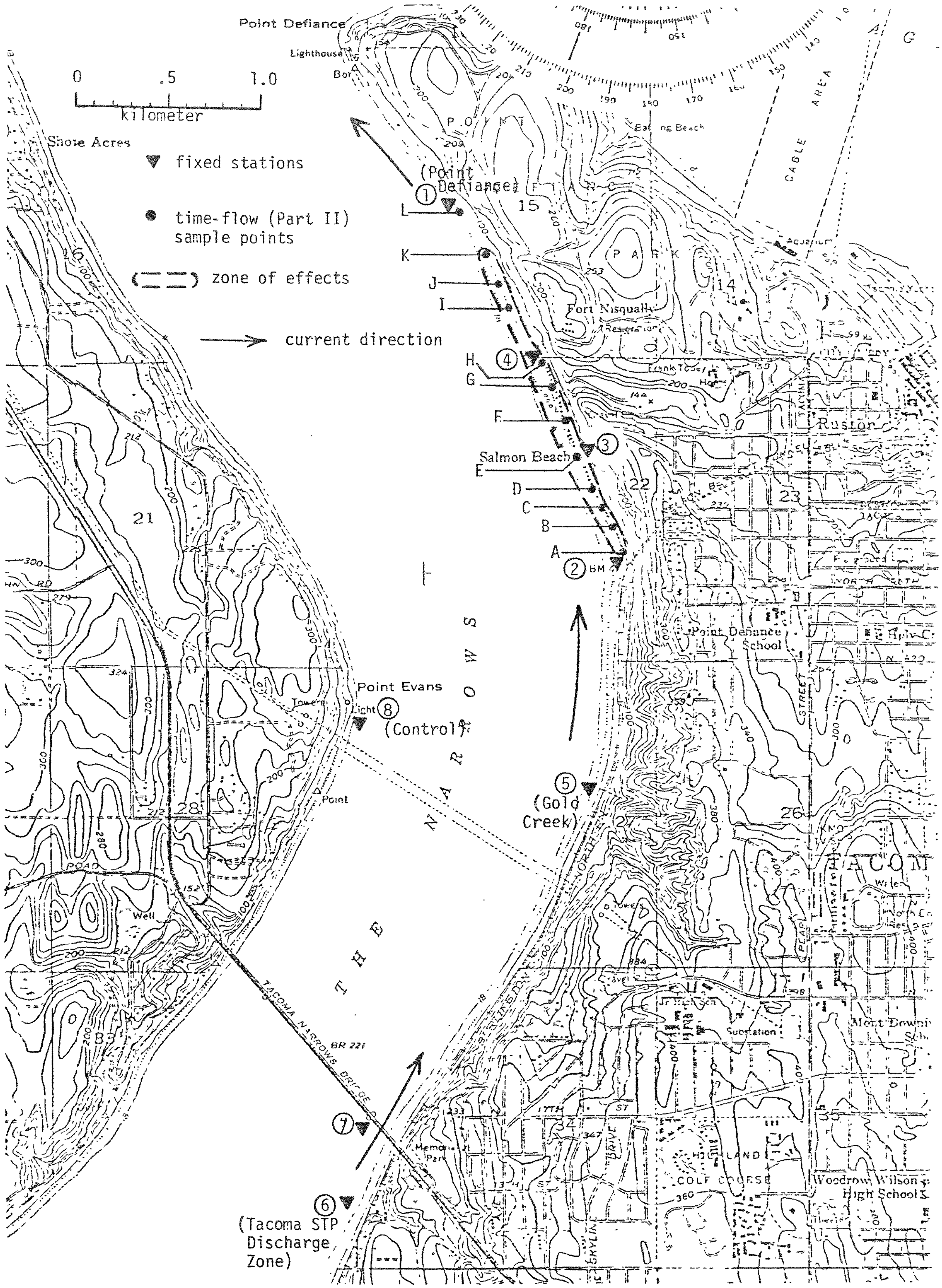

Figure 1. Tacoma Narrows study area showing both fixed stations and time-flow (Part II) sample points. A zone of effects associated with Salmon Beach waste disposal practices is shown. Current direction shown occurred during rising tide.

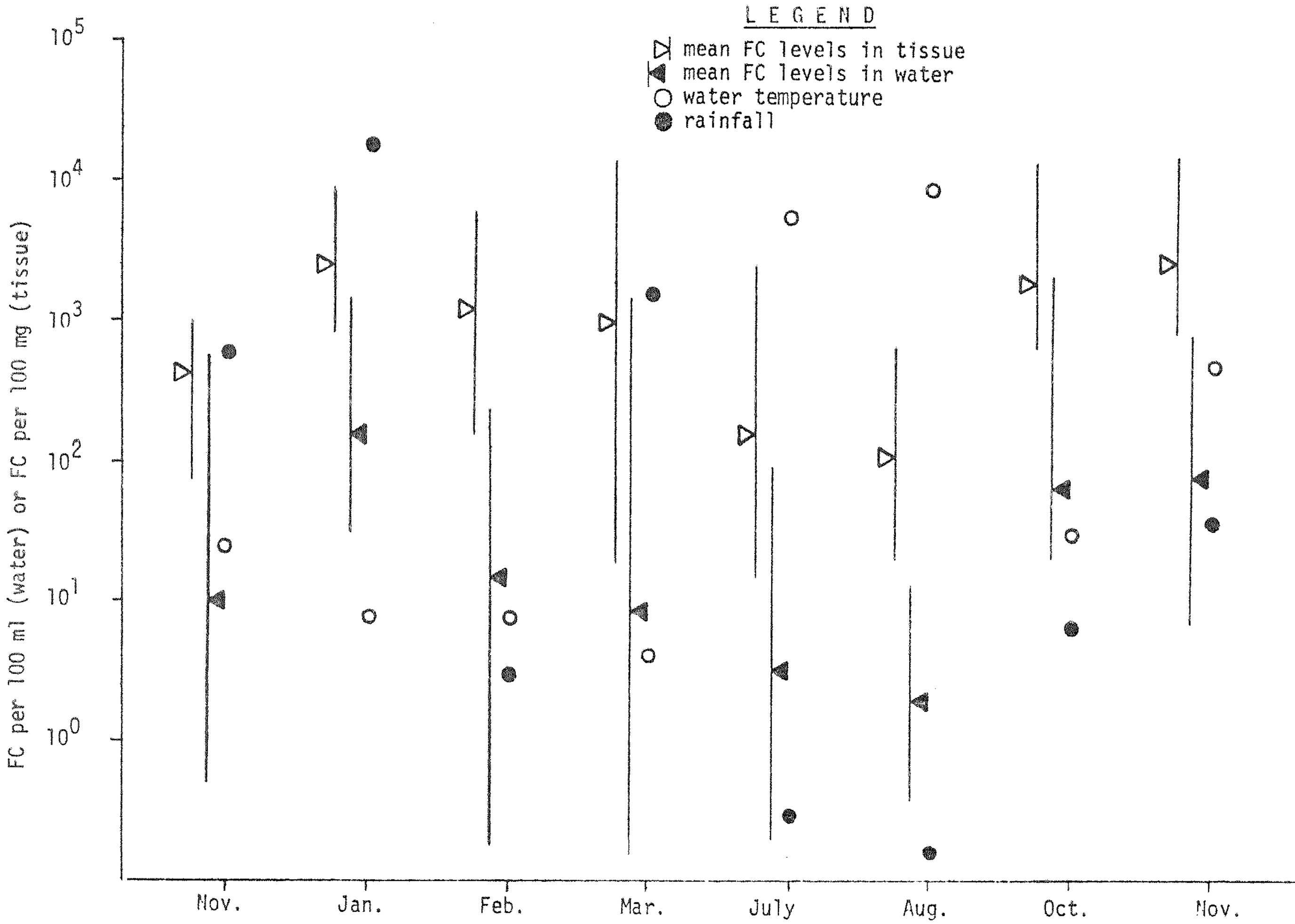

Figure 2. Means and ranges for fecal coliform levels in Manila clam tissue and water collected during stud
conducted by Vasconcelos, et al., (1969). Rainfall and water temperature data are shown also.

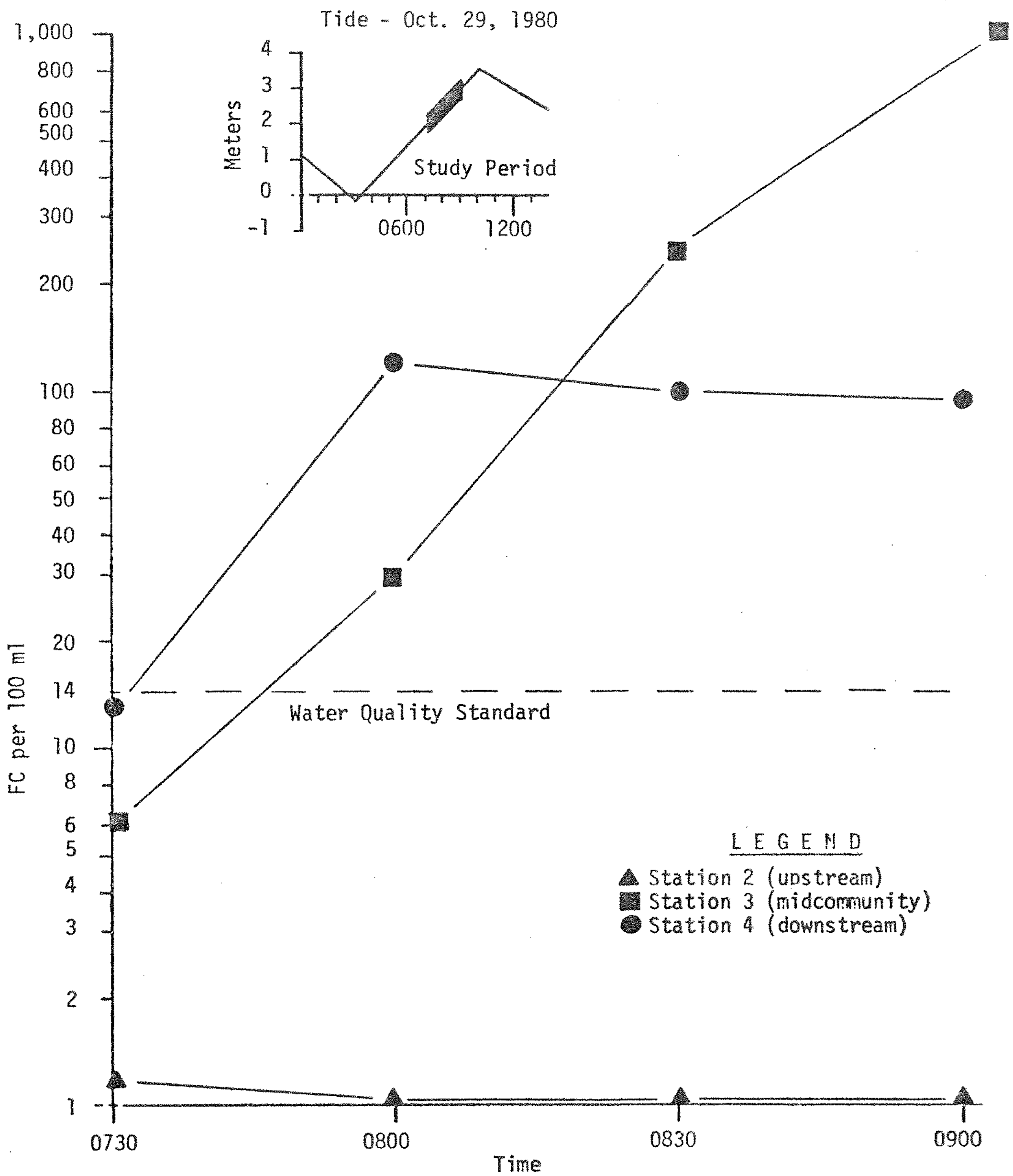

Figure 3. Fecal coliform time-series study (Part I) at Salmon Beach on October 29, 1980. Data are based on single samples taken at half-hour intervals.

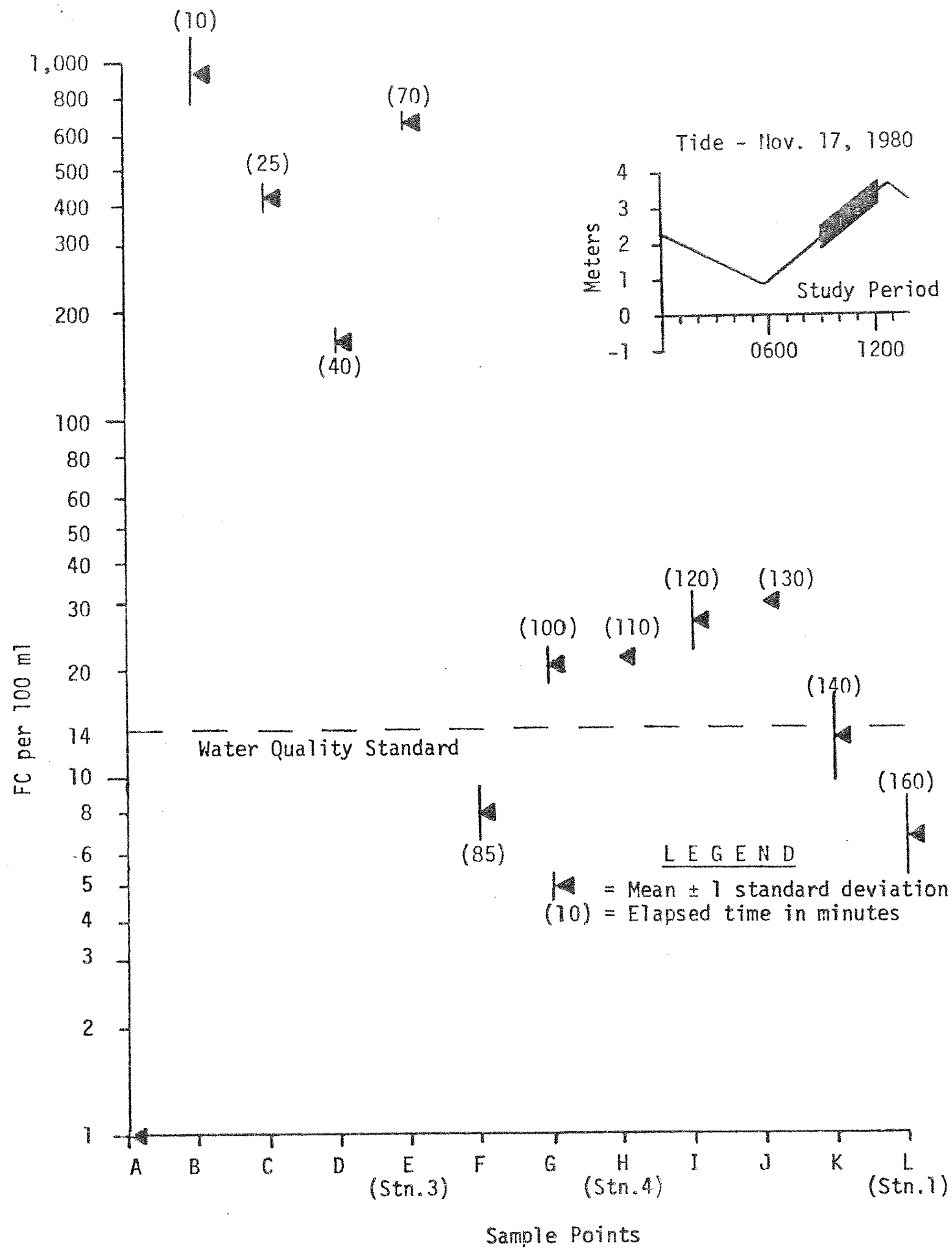

Figure 4. Fecal coliform results taken during a DOE dynamic flow study (Part II) conducted at Salmon Beach on November 11, 1980. Two replicates were taken at each sampling point. Sampling points are shown in Figure 1.

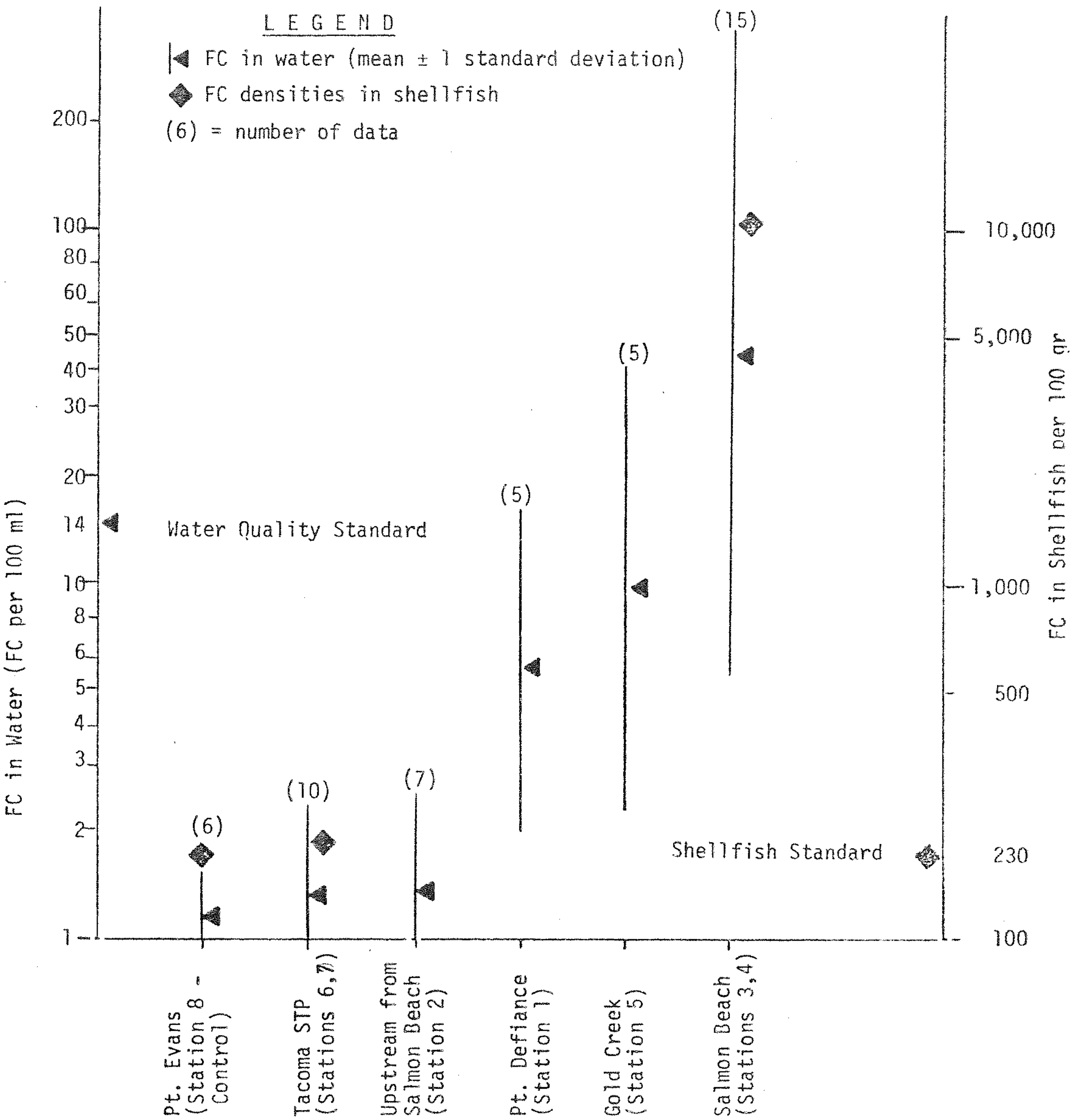

Figure 5. Fecal Coliform (FC) data for water and shellfish for several areas in Tacoma Narrows. The data are ranked from lowest to highest. Number of data at each station is shown in parentheses.