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SOURCES AFFECTING BACTERIA QUALITY IN OAKLAND BAY
FINAL REPORT

by

Joy P. Michaud

Washington State Department of Ecology
Water Quality Investigations Section
Olympia, Washington 98504-6811

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ABSTRACT

A recent water quality survey of Oakland Bay in Mason County, Washington, prompted the revision of the shellfish harvesting classification due to high bacteria concentrations. Further investigation resulted in discovery of a number of potentially important bacteria sources. These were stormwater discharges, industrial effluent, and two creeks that flow into the inner harbor. An estimate of the importance of each bacteria source is made. Their relationship to wet-weather conditions also is discussed, although relatively dry weather was experienced during the investigation. Recommendations for source control and further investigative efforts are made.

INTRODUCTION

Oakland Bay in Mason County, Washington, has historically been an important part of the shellfish industry in Washington State. The Bay was the center of the Olympia oyster industry until the decline of the oyster population in the 1930s. Native and littleneck clams eventually became established in the Bay, but were not commercially harvested for many years due to inadequate sewage treatment at the old Shelton wastewater treatment plant (WTP) (DSHS, 1984). In 1979 when the new WTP began operation, the northern end of the Bay was "Conditionally Approved" for commercial harvest of shellfish by the Department of Health and Social Services (DSHS). There are currently six commercial shellfish operations that harvest from the "Conditionally Approved" ground in Oakland Bay. Together they accounted for 42 percent of the state's hardshell clam production in 1986 (E. Hurlburt, personal communication).

DSHS is responsible for evaluating the sanitary quality of commercial shellfish-growing waters in Washington. The evaluation and approval is based on periodic bacteriological studies of the water. Standards are set by the U.S. Food and Drug Administration (USDHHS, 1986) (Table 1). DSHS conducted an intensive water quality survey in Oakland Bay during December 1986 and January 1987 as part of their routine monitoring program. Survey results indicated a bacterial contamination problem, and the Bay was reclassified as "Restricted" (Table 1).

In February 1987, the Department of Ecology began to investigate source(s) of bacteria to the Bay. The investigation centered on the inner harbor where bacteria levels were highest (DSHS, 1987). The investigation included:

- An inventory of pipes discharging to the inner harbor.
- Monitoring streams flowing into the inner harbor and their watersheds.
- Evaluating the magnitude and extent of bacterial pollution from each source.
- Assessing the seasonality of the bacterial pollution problem and its relation to point or non-point sources.

Table 1. Classification of Shellfish Growing Areas (USDHHS, 1986).

Approved	Approved for growing or harvesting shellfish for direct marketing.	Geometric Mean less than or equal to 14/100 mL and not more than 10 percent of samples exceed 43/100 mL for a five-tube, three-dilution test.
Conditionally Approved	Approved for growing or harvesting shellfish during predictable periods when the area meets "Approved" area conditions. Approval based on performance standards specified in a management plan.	Must meet "Approved" area standards during periods when it is open to harvesting.
Restricted	Shellfish harvest allowed only if permitted, and shellfish are subjected to a suitable and effective purification process.	Geometric mean less than or equal to 88/100 mL with not more than 10 percent of samples exceeding 260/100 mL.
Prohibited	Closed to the harvesting of shellfish at all times.	Bacteria concentrations exceed "Restricted" area limits, or where pollution sources may unpredictably contaminate the area.

As a result of efforts by Ecology, ITT Rayonier, Simpson Timber Company, and the city of Shelton, plus recent surveys by DSHS (G. Plews, personal communication), Oakland Bay has regained its "Conditionally Approved" status. Conditional Approval is now dependent upon ITT Rayonier's effluent quality, the city of Shelton's stormwater quality, and possible malfunctions at the Shelton WTP. Any significant deterioration in the amount or quality of any of these discharges will be reported to DSHS, and reclassification will be considered.

This report summarizes: the results of the Ecology investigation; progress made on controlling the important bacteria sources; and plans and recommendations for the project area.

DESCRIPTION OF THE STUDY AREA

Oakland Bay in Southern Puget Sound is about four miles long and three quarters of a mile wide at its widest point (Figure 1). It flows into the northern end of Totten Inlet via Hammersley Inlet. The outer bay is a Class A water, and the inner harbor area (west of longitude 123° 05' W) is a Class B water, and as such must meet state water quality standards for these classifications.

A flushing study of the Bay was done for part of one tidal cycle in June of 1974 (Department of Health Education and Welfare, 1975). The researchers concluded "there does not appear to be much displacement by different water" and "it is conceivable that most of the same water in Oakland Bay could move up and down the bay with the tides." Although these results are not conclusive due to the limited duration of the study, they indicate that pollutants may take a long time to be "flushed" through the bay.

The city of Shelton is located at the southern end of the Bay. Simpson Timber Company, ITT Rayonier Research Laboratory, and Manke Lumber Company are all located along the shoreline of the inner harbor. Goldsborough and Shelton Creeks and the city of Shelton stormwater discharge to the harbor. The new WTP and discharge are located east of the inner harbor on the south side of the Bay.

Goldsborough Creek flows through Shelton, but is flanked on its southern side by a steep ravine and on its northern side by railroad tracks. Consequently, there is little development close to its banks. However, stormwater from Shelton and the inner harbor industrial area is discharged to the creek in a number of places. Goldsborough Creek flows into the center of the inner harbor shoreline (Figure 2).

Shelton Creek drainage is more complex than Goldsborough. The northern tributary of Shelton Creek contributing the greatest flow (called Town Creek) originates in a marsh northeast of the city of Shelton. It passes through a deep, wooded ravine, then through town where it joins the western tributary (Figure 2). The western tributary originates from two forks (Figure 2). Both forks form part of the stormwater system and flow underground for most of their course through town. Their approximate path is shown in Figure 2 as a dotted line. The stormwater discharges and the creek's proximity to the urban environment increase the probability of impact from failing septic systems, sewer line leaks, or misconnections. Shelton Creek flows into Oakland Bay along the northern edge of the inner harbor (Figure 2).

City stormwater directly enters the inner harbor through a 54-inch culvert located south of Goldsborough Creek. Stormwater from the inner harbor industries is discharged to the harbor and the two creeks through separate stormwater pipes.

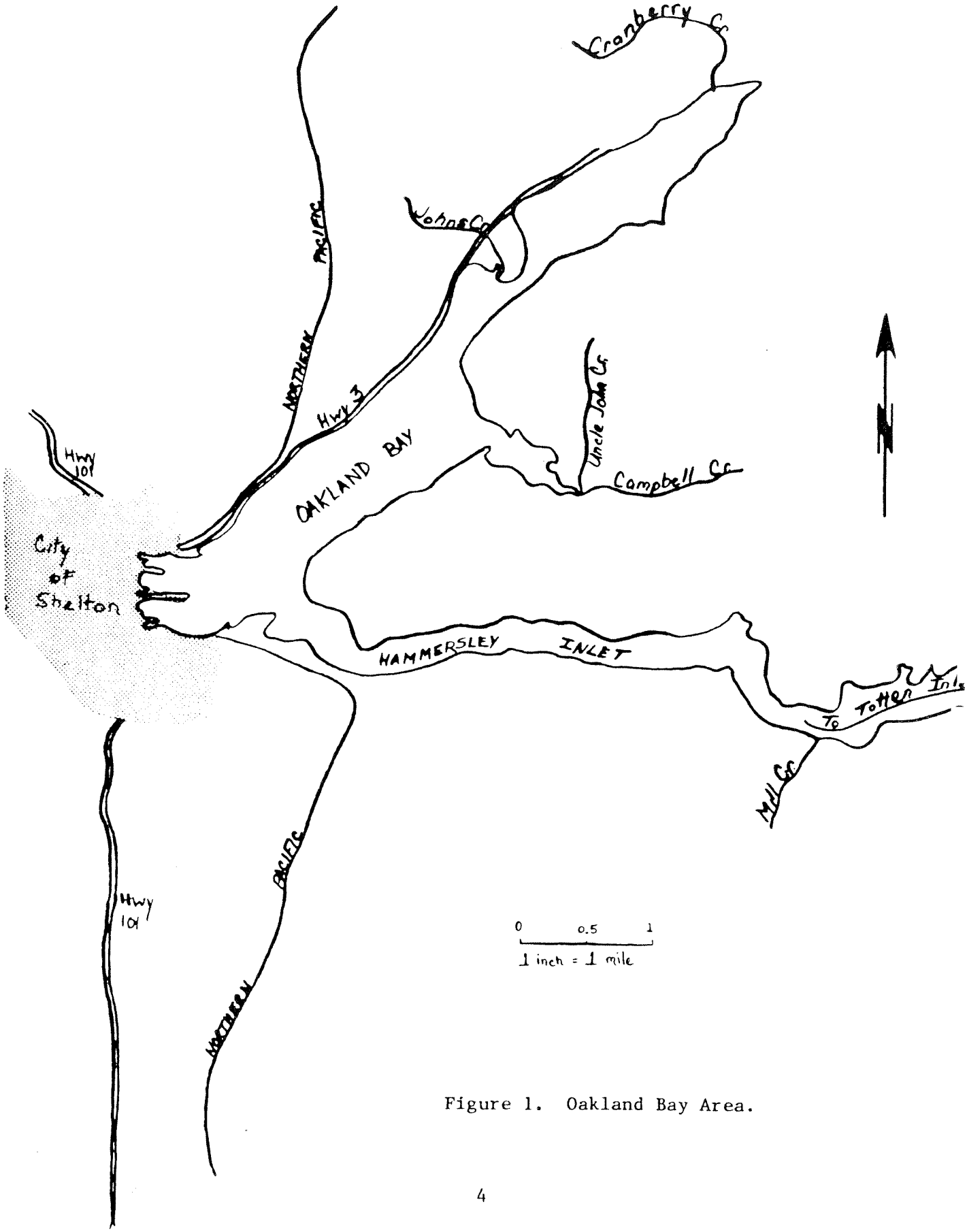


Figure 1. Oakland Bay Area.

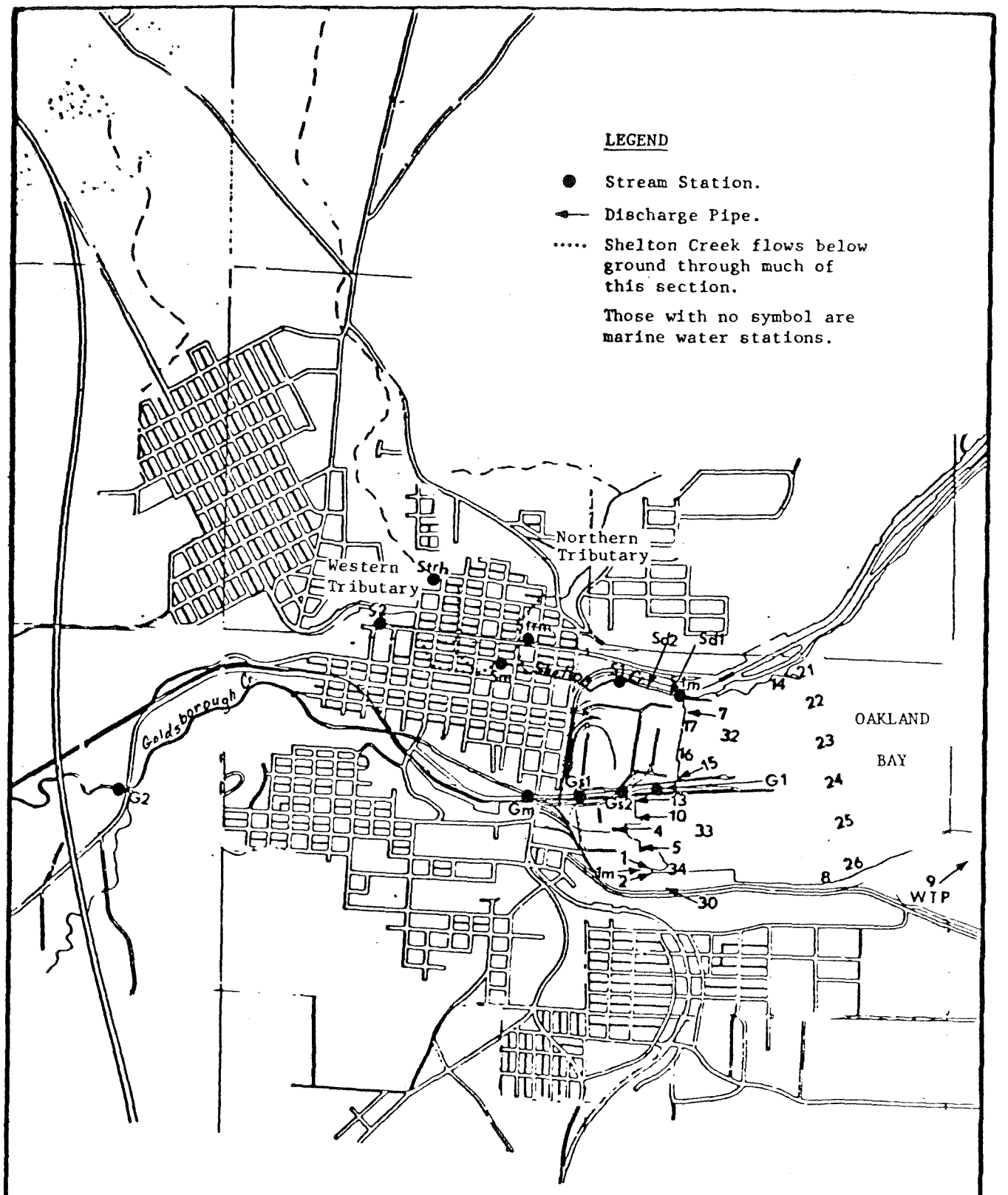


Figure 2. Location of stations sampled during the Oakland Bay investigative study.

There are five active National Pollutant Discharge Elimination System (NPDES) permits regulating discharges to the Bay.

- The existing permit for the ITT Rayonier research facility limits biochemical oxygen demand (BOD), total suspended solids (TSS), pH, temperature, and discharge volume. The discharge complies with these requirements.

- The Shelton WTP NPDES permit limits TSS, BOD, pH, temperature, flow, fecal coliform (FC) bacteria, and residual chlorine. The plant is presently not meeting its percent removal limits for TSS during wet-weather conditions when wastewaters are diluted by excessive infiltration and inflow (I&I).

- Simpson Timber Company has three permits for non-contact cooling water discharges. Simpson is required to monitor flow, temperature, and oil and grease in their effluents. These parameters are in compliance with their permit. Simpson's process wastewaters are discharged to the Shelton sanitary sewer.

METHODS

Source Inventory

A reconnaissance of the inner harbor was made to map the location of discharge pipes, estimate flow where possible, and collect FC samples. Volumes and concentrations were used to rank each pipe as an FC source. Later sampling concentrated on the largest sources, although as many pipes as possible were sampled on each trip. Sampling occurred on nine days: February 25; March 2, 4, 10, 18, and 31; April 15, and 28; and May 27. (All but two samples from March 10 were lost due to lab error.)

Shelton and Goldsborough Creeks were also monitored. Sampling stations were set up near the mouth of each creek and at selected upstream points. Fecal coliform samples were collected at each site, and flows measured when possible. Flow was estimated by measuring depth, width, and velocity in a cross-section of the stream. Velocity was measured with a Model 2100 Swoffer meter. The data were used to calculate the total discharge volume. Discharge volume and concentration were used to estimate FC bacteria loading to the inner harbor.

Samples were also collected from the inner bay to monitor water quality in relation to the discharge sources. Collection occurred during ebbing tides to minimize the effects from potential outer bay sources.

Analytical

Fecal coliform bacteria concentrations were measured using the membrane filter (MF) technique (APHA, 1985). Some bacteria that test positive using this technique may be unrelated to fecal waste. An additional test is used to determine what percentage of the fecal coliform bacteria concentration can be attributed to bacteria not always associated with fecal waste. The results are reported as %KES, where KES represents the bacteria *Klebsiella* sp., *Enterobacter* sp., and *Serratia* sp. This test was used during the investigation to aid in distinguishing bacteria sources.

Quality Assurance

DSHS uses the multiple-tube fermentation (MPN) procedure for FC analyses. Both MPN and MF tests are approved standard methods (APHA, 1985). Samples collected along the inner harbor transect on March 18 were analyzed using both, and the results compared.

Replicate samples were occasionally taken and split with ITT when monitoring their effluent. The replicate samples were analyzed for ITT by a private laboratory in Seattle, Washington, using the MF test.

Weather

Daily precipitation is recorded at the ITT Rayonier research facility in Shelton, Washington. Historical data were retrieved from monthly summaries of "Climatic Data for Washington" (N.C.D.C. 1979-1986).

Precipitation data for 1987 was obtained from ITT. This information was used to differentiate between wet- and dry-weather sampling events and to estimate watershed moisture conditions.

RESULTS AND DISCUSSION

Weather

Many pollutant sources are affected by wet weather. During periods of heavy rain and saturated soils, there are increases in septic system failures, stormwater runoff, and sanitary sewer overflows. With the exception of the March 2 and 4 sampling dates, the investigation occurred during fairly dry weather (72 hour rainfall totals for each sampling data are given in Table 2). Consequently, wet-weather impacts have not been fully accounted for during this investigation. Goldsborough and Shelton Creeks and industrial site stormwater discharges, as well as the City stormwater discharge, would all be affected by wet-weather conditions.

Table 2. Fecal coliform concentrations (FC/100 mL) and percent KES measured at the sampling locations shown in Figure 2. (Percent KES results are in parantheses.)

	2/25	3/2	3/4	3/18	3/31	4/15	4/28	5/27	Geometric Mean	Flow Range (cfs)	Loading* (#/day x 10
72-hour Rainfall**	0.00	2.44	4.43	0.68	0.00	0.84	0	0			
STATION											
Source Samples											
1	81,000 (0)		12,000 (100)	22,000 (100)	34,000 (100)	36,500 (100)	10,000 (100)	18,300 (100)	24,200	0.47-1.03	1,150-20,4(
1M			24,000 (100)		27,000 (100)				25,460		
Manke				3,000***							
4	570 (8)		56,000 (1)	<4 (0)	11 (0)	1200	180 (0)	9	132	0.74-2.16	0-29,600
5	9 (0)			8 (0)			3		6	0.05	0.073
7	11 (0)			290 (100)	15	>600 (50)	34 (86)	4,000	>126	0.10-0.16	0.269-157
9	45		210		55	2	6	<3	14		
10	15 (0)			8	4			6	7	0.32-1.10	0.313-4.04
13	<1			3,000*** (0)	<1		<1		7	0.01	0-7.34
30			<4								
Bay Samples											
8						97	34		57		
14			240	<7	6	6	72		14		
15				70 (31)	140 (31)	2,200 (3)	6 (50)		107		
16				6 (0)	48	130 (0)	130 (0)		47		
17				<2 (0)	120	3,200 (50)	4 (0)	<3	17		
21				2							
22	3 (6)		180	7	54	8	20	14 (0)	17		
23				10 (40)	66				26		
24	1 (0)		41	12	96	76	80 (5)	100	31		
25	1 (0)		59	<4 (0)	53	150	46	23	17		
26				18				34 (0)	25		
32				28 (0)	22	8	6 (0)		13		
33				6 (0)	60	56	6 (20)	180	29		
34	1,100 (0)		2,600		48 (58)	5,200	<10	700 (100)	280		
Shelton Creek											
Slm				360	2,500	260	23	69	206		
Sd(1)				6,700	8	60	19	3	45	0.06-0.61	0.04-1,000
Sd(2)				1	>600	2,100	340	290	166	0.14-0.63	
Sl	15	500	75	75	20	230	26	20	56	6.53-21.8	24-2,667
Sm	1	270	80		8	79	1	<3	11	2.54-5.20	0-344
Strm		670	60		43	150	43	270	120	3.57-25.7	38-4,223
Strh		60									
S2	1	192	108					3	16	3.30-4.70	2-221
Goldsborough Creek											
Gl	47		43		84				55	1,158	23,801(max)
Gsl		96									
Gs2		130					6	92	42		
Gm	3	86	35	10	12	44	7	6	15	63.3-183	47-3,866
G2	5	69	33				6	40	19	126.8	2,141(max)

*Loading was calculated using the range in flow and minimum and maximum concentrations.
**72-hour rainfall includes the day of sampling plus the two preceding days.
***Sample collected on March 10, 1987.

Goldsborough Creek

Although Goldsborough Creek flows through the city of Shelton, little development has occurred directly on the shoreline. However, stormwater is discharged to the creek from the City, ITT Rayonier, and Simpson Timber Company. Consequently, there is potential for bacterial contamination.

Flow data collected during the investigation are sparse due to wading difficulties experienced during high flow. Flow in the lower portion of the creek was variable, ranging from 63 to 1100 cfs. Fecal coliform concentrations in the lower portion of the creek (Stations G1, Gs1, Gs2 in Table 2 and Figure 2) were similar to those collected upstream of the industrial portion of the inner harbor but downstream from the City stormwater discharges (Station Gm). Therefore, stormwater discharges from the industrial sites did not appear to significantly impact bacteria concentrations downstream. (A winter high-flow study may result in different conclusions.) Fecal coliform concentrations at Station G2, located upstream of all City stormwater discharges, were also similar to downstream stations. Measured bacteria concentrations in Goldsborough Creek met the freshwater Class A requirements. ("Fecal coliform organisms shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of samples exceeding 200 organisms/100 mL.") As will be discussed later, due to the size of the creek in relation to the other discharges monitored, Goldsborough Creek is a major contributor of bacteria loading to the inner harbor.

Shelton Creek

Results from Shelton Creek are in Table 2; sampling stations are shown in Figure 2. Stations Sm and Strm were located on the western and northern tributaries, respectively, a short distance upstream of their confluence. Comparison of the data from the two tributaries indicate the northern tributary is the more important bacteria source. It had consistently higher concentrations and larger, more variable flows. The western tributary had one high concentration measured at Sm on March 2 during a period of wet weather. All other samples were low. The large flow variation measured in the northern tributary as compared to the western tributary may indicate it has a larger or possibly more developed watershed. If this is the case, it would be more responsive to rainfall events and more likely to exhibit rainfall-related water quality impacts.

Sampling station Slm was located closest to the mouth of Shelton Creek. Bacteria concentrations were often very high at this point. The concentration at this station reflects the concentrations at Station Sl upstream and contributions by two culverts (Sd1 and Sd2) that flow into Shelton Creek between stations Sl and Slm. Sd2 had consistently high FC concentrations. This source will be discussed in more detail below.

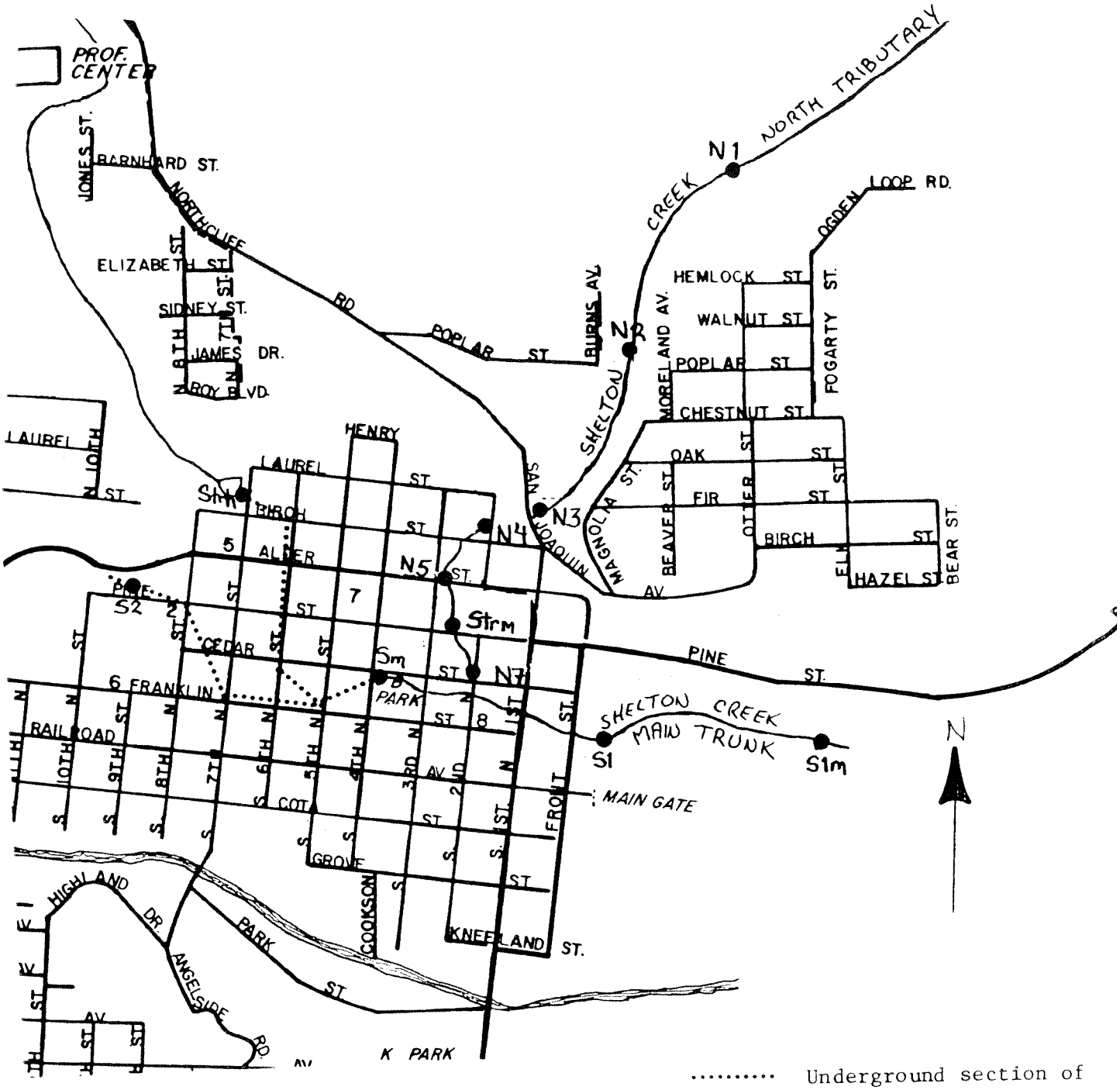
Due to the complexity of the Shelton Creek system and its apparent importance as a bacteria source, additional sampling of the northern tributary and the lower portion of Shelton Creek was conducted. In an effort to determine the important loading segments, samples were collected at seven sites (Figure 3) on April 15 after a moderate (0.84 inch/72 hr.) rainfall. Bacteria concentrations ranged from 100 to 220 FC/100 mL. All sites violated Class A water quality standards. Samples were also collected from two or three of the seven sites on two days (April 23 and 28) when no rainfall had occurred (0.00 inch/72 hr.). Although the upstream station (N3) had low concentrations, the downstream stations (Strm and N7) remained somewhat high. Data are in Table 3.

Table 3. Summary of data from sites sampled in the northern tributary and lower portion of Shelton Creek. Stations correspond to those shown in Figures 3 and 4.

Station	Date						
	March 2	March 4	March 18	March 31	April 15	April 23	April 28
N1					220		
N2					190		
N3					100	20	<5
N4					160		
N5					140		
Strm*	670	60		43	220	40	120**
							43
N7					200	160	
Ls1					3		
Ls2					3		6
Ls3							3
Ls4						3	
Sd1*			6,700	8	60	4	19
Ls5					100		
Ls6							71
Ls7							3
Sd2*			1	>600	2,100	220	340

*These stations are part of the routine monitoring program, consequently there are more data available for them. All the data for the stations are reported here to aid in comparisons.
**Two samples were collected from this station on the same day.

Additional sampling was done in the lower portion of Shelton Creek to ascertain the source of flow to the two culverts; Sd1 and Sd2. Sd1 appears to be primarily a discharge from a pond located between Highway 3 and the railroad track that parallels the lower creek (Figure 4). The pond is fed, via culvert, by drainage collected on the north side of the highway. Except for the March 18 sampling of Sd1, bacteria



..... Underground section of Shelton Creek.

Figure 3. Location of sampling stations on Shelton Creek and its tributaries. Dotted line shows approximate path of the western tributary. Much of this portion of the Creek flows below ground.

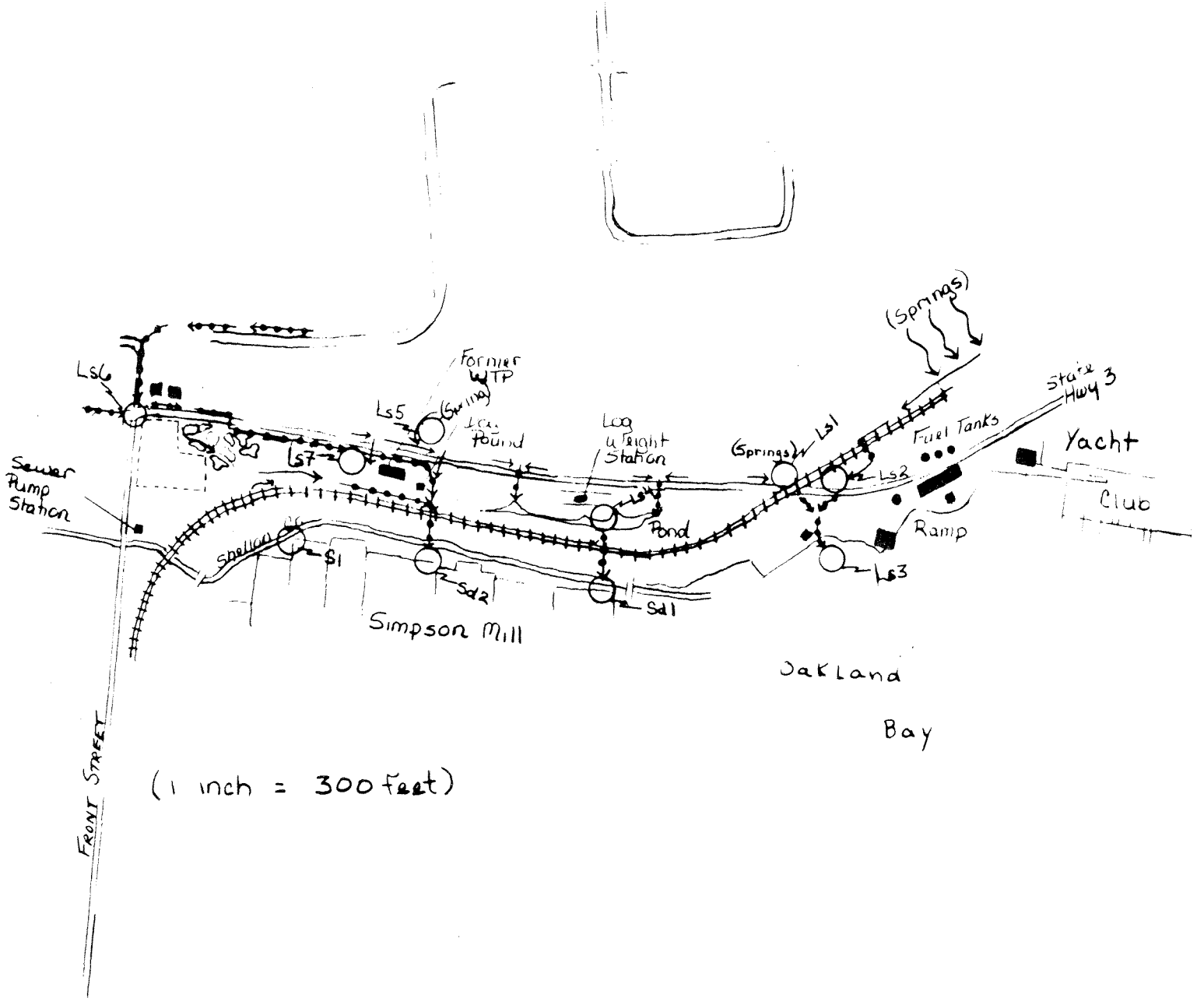


Figure 4. Lower portion of Shelton Creek showing location of sampling stations.

concentrations in the pond and the drain (Sd1) have been low (Table 3). Conversely, bacteria concentrations at Sd2 have been very high. Flow at Sd2 comes from at least two sources; stormwater runoff (Station Ls6) and a salt marsh located just west of the former wastewater treatment plant (Station Ls7). The flow at Station Ls6 on April 28 (during a dry period) was 0.08 cfs. At that time, tne flow was coming exclusively from the Capitol Hill area. Presumably, during heavy rainfall, additional flow would come from downtown streets. The flow at Station Ls7 was 0.02 cfs; it was fed by both the salt marsh and a spring-fed ditch located on the north side of the highway (Station Ls5).

The flow at Sd2 (0.41 cfs) far exceeded the sum of the flows of the two measurable sources (0.10 cfs). Although it was not possible to measure discharge at Station Ls5, it was very small compared to Stations Ls6 or Ls7. This indicates there is another source to Sd2. This is supported by the bacteria data. The bacteria concentration at Sd2 was 340 FC/100 mL on April 28, while the concentration at Station Ls6 and Ls7 was 3 and 71 FC/100 mL, respectively. Even assuming the concentration was 100 FC/100 mL at Station Ls5 (measured during the April 15 wet-weather sampling), this still would not account for the concentration measured at Sd2.

A large culvert discharges to the inner harbor just beyond the mouth of Shelton Creek (Ls3). The discharge is fed by two drains located on the north side of Highway 3 (Ls1 and Ls2). These sources were verified using Rhodamine wt dye. FC concentrations from both drains were very low (Table 3).

City of Shelton WTP and Storm Sewer Systems

The Shelton WTP discharges at Eagle Point (Figure 1) and therefore is not an inner harbor bacteria source. Nonetheless, the WTP was monitored during the study. Fecal coliform concentrations were typically low (Station 9, Table 2). Routine monitoring of the effluent has indicated that bacteria concentrations are consistently low and meet permit requirements (D. Anderson, personal communication). As discussed earlier, TSS violations occur seasonally.

During periods of heavy rain, the flow in Shelton's sanitary sewer often exceeds line capacities. This causes overflow into the stormwater system and bacterial contamination. Known overflow points are marked in Figure 5.) The overflows are caused by excessive ground water I&I. Saturated soils exacerbate the condition. I&I increases as collection systems age and develop faulty joints and leaks. According to a 1975 study of the city of Shelton collection system (Kramer, Chin, and Mayo, Inc., 1975), infiltration was found to be excessive and collection system rehabilitation was recommended.

City stormwater discharges to the inner harbor through a 54-inch culvert located south of Goldsborough Creek (Station #4, Figure 2). The magnitude of the stormwater problem is illustrated by the March 4

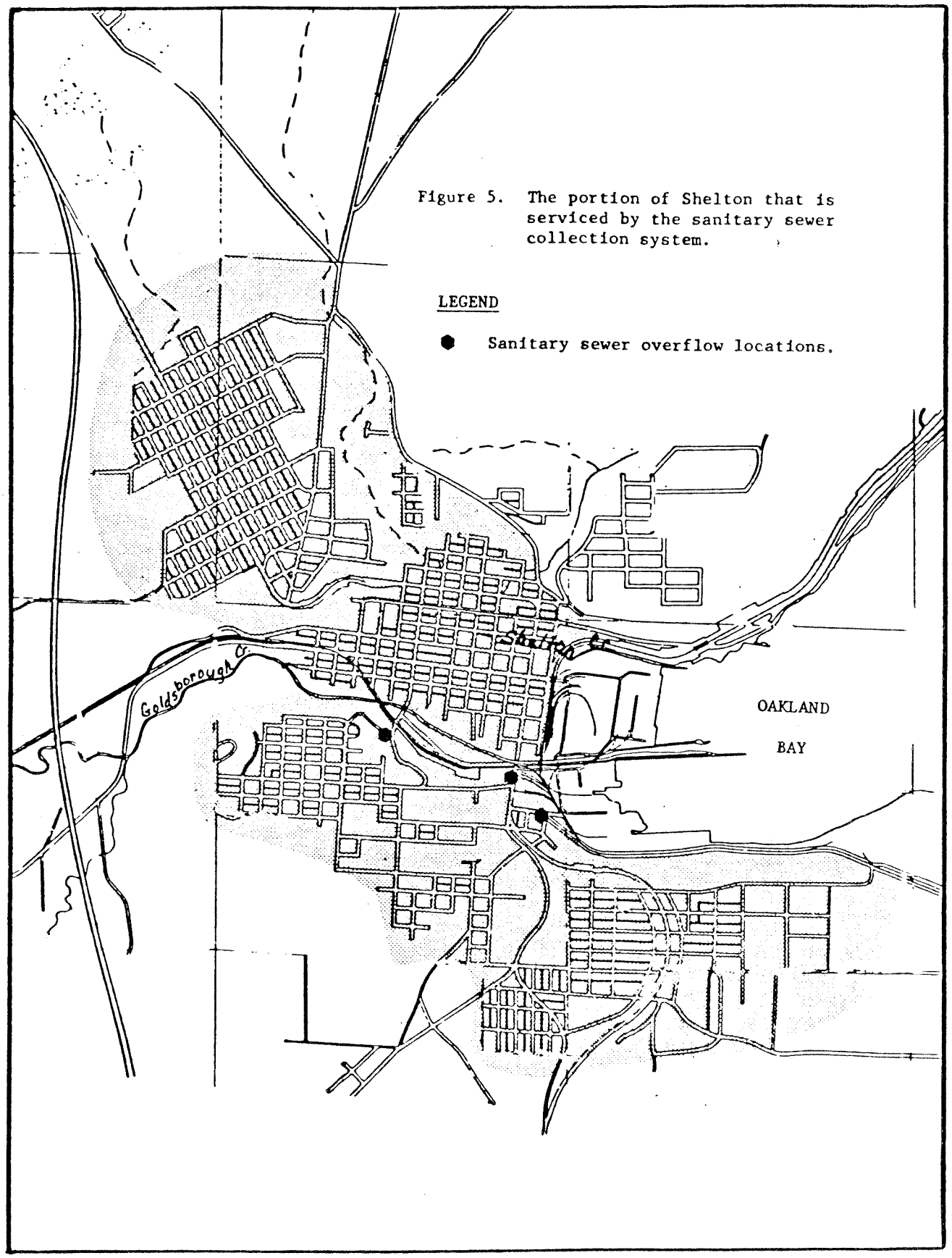


Figure 5. The portion of Shelton that is serviced by the sanitary sewer collection system.

sample from Station #4 which had a fecal coliform bacteria concentration of 56000 FC/100 mL. Sanitary sewers were known to have been overflowing at the time. Although no discharge data are available for March 4, the volume would have been very high since 4.4 inches of rain fell for three days prior to sampling. Dry weather (low flow) samples collected at the same site during late March were very low (<4 and 11 FC/100 mL).

The shaded area in Figure 5 depicts the portion of Shelton that is connected to the sanitary sewer system. Residences or businesses located outside the shaded area can be assumed to be using on-site septic systems. Due to the problems typically associated with on-site systems (failure due to age, design, or lack of proper maintenance), the unsewered portion of the City represents a potential source of contamination. This may be especially important to the lower end of Shelton Creek which receives runoff from the unsewered area.

The city of Shelton is actively dealing with the bacterial contamination problem. Surveys have been conducted of the stormwater system. As a result, the City removed a sanitary line mistakenly connected to the stormwater system, and repaired a porthole that allowed sanitary wastes to enter the stormwater system. A private consultant has also been hired to study their current I&I problems.

The City and Mason County have jointly applied for and been awarded a grant from the Department of Ecology. The grant study involves:

- Septic system surveys of unsewered portions of Shelton.
- A shoreline survey of Oakland Bay.
- Identification of agricultural runoff into Oakland Bay.
- Further monitoring of the stormwater system and identification of I&I sources.

ITT Rayonier

The ITT Rayonier discharge (Station #1, Figure 1) is primarily composed of laboratory wastes, although some stormwater may also be discharged via the outfall line. Fecal coliform concentrations were always very high in the discharge. To determine whether the bacteria were originating from the stormwater or laboratory wastes, samples were collected from a manhole downstream from the lab and upstream of the stormwater entry point (Station #1M, Table 2). These were compared to end of the pipe samples (Station #1). Results indicated there was no difference between the sites considering the natural variability of the data. Thus, the high bacteria concentrations were assumed to be from the lab waste stream. ITT determined that the bacteria were coming from a large equalization tank located near the end of the discharge line. Efforts to disinfect the tank and other

parts of the collection system with chlorine were unsuccessful. The type of FC bacteria found in the ITT discharge is Klebsiella spp., a species commonly associated with pulp wastes. These bacteria seem to be tolerant of chlorine, probably as a result of contact with it during the pulp bleaching process. Disinfection can also be achieved by lowering effluent pH. This is a fairly safe method in marine waters where pH changes are quickly buffered. Currently, ITT Rayonier is testing this method of disinfection by reducing effluent pH by small increments and measuring changes in bacteria concentrations. They are also monitoring pH in the inner harbor a short distance (approximately 150 feet) from their discharge to ensure there is no impact.

Simpson Timber Company

There are three cooling water discharge permits for Simpson Timber Company currently on file with Ecology. Two of the discharges have been combined, so only two "permitted" pipes remain. (These are shown in Figure 2 and Table 2 as #7 and #10.) Discharge #10 had an estimated flow of 0.32 to 1.10 cfs, and had consistently low FC concentrations. The flow at discharge #7 ranged from 0.10 to 0.16 cfs, and the bacteria concentration was highly variable. This discharge pipe carries stormwater as well as non-contact cooling water. The cooling water is to be eliminated from discharges #7 and #10 during the next few months. It will become evident at that time what the source is (was) of the high bacteria counts.

Pipes #13 and #15 are also stormwater discharges. The bacteria count was high in #13 during one rain event, but counts were below detection on all other sampling dates. Direct measurements of flow from this pipe have not been possible, but it appeared to be very small. Like other stormwater discharges, flow and bacteria concentration may increase greatly during wet weather.

Fecal coliform concentrations in pipe #15 have varied. It is not clear whether the higher concentrations are related to rainfall. Studies done by Simpson have shown that this pipe was previously connected to the City's stormwater system. The connection was plugged, but it is possible that the plug is no longer watertight (J. Soehnlein, personal communication). By sampling both of these discharges (#13 and #15) during wet weather, the extent of change to both volume and concentration of the discharges could be monitored.

Simpson Timber Company has done extensive on-site monitoring to locate possible bacteria sources. Some stormwater samples have had high FC concentrations. It was expected that these bacteria would belong to the Klebsiella spp. group, as found in the ITT discharge. Instead, results have varied, and Klebsiella has sometimes represented only a small portion of the fecal coliform population (J. Soehnlein, personal communication). A study was done to test whether there was a possible misconnection in the sanitary sewer line that was allowing discharge

of sanitary wastes to the stormwater system. The sewer line was plugged to simulate overflowing conditions, and dye flushed into the system. Samples were then collected from within the stormwater system and where the stormwater discharges into the inner harbor. A fluorometer was used to check for signs of the dye; no dye was observed during the study, although bacteria concentrations (primarily Klebsiella spp.) remained high at the stormwater discharge points (J. Soehnlein, personal communication).

High FC concentrations with low KES percentages have occasionally been measured in the inner harbor near the stormwater discharges (Stations #15, #16, and #17, Table 2). This indicates a fecal source for the bacteria. Because the results from both Ecology's and Simpson's sampling are unclear, and Simpson is in the midst of changes that may impact bacteria concentrations (e.g., removal of cooling water discharges, cleaning out stormwater lines, and pavement of the log storage area at the back of their property), further investigation should be conducted after these improvements have been made, during the winter high-flow period.

Miscellaneous Sources

A one-time sample of stormwater runoff from Manke Lumber Company property had a very high FC concentration. Dry weather and low runoff volumes precluded additional sampling. The Southwest Regional Office (SWRO) of Ecology has been working with Manke on control of truck wash water and stormwater. A conceptual plan has been agreed upon, although no details of the plan have been presented (G. Cloud, personal communication). Further monitoring of the runoff during wet weather is necessary to determine its importance as a bacterial loading source.

The Shelton Yacht Club, located on the north shore of the inner harbor, has an on-site septic system. Reports of surfacing effluent have been made but not verified, and the few samples collected near the yacht club have had low bacteria concentrations. Future investigation efforts should include sampling near the club during wet weather to determine the systems effectiveness and possible impact on water quality.

Harbor Water Quality

Nearshore and mid-harbor sampling stations #8, 14, 16, 17, 32, 33, and 34 are shown in Figure 2. All stations have had consistently low bacteria concentrations, with a few exceptions. Stations #16 and 17 are located within 20 feet of shore near the Simpson Timber Company stormwater discharges. These stations were high on April 15 during a rain event. Station #14 was also high on March 4 during a period of heavy rains. This station is located near the yacht club and marina and may reflect these sources. Station #34 is located approximately 150 feet directly in front of the ITT outfall. Bacteria concentrations here were almost always high compared to other inner harbor stations (Table 4). Differentiation of FC bacteria indicated the type

Table 4. Comparison of inner harbor samples to marine water Class B water quality standards for fecal coliform bacteria. Number of samples is shown in parentheses.

	Station	Geometric Mean	Percent Greater Than 200
DSHS Transect	21	2 (1)	0
	22	17 (7)	0
	23	26 (2)	0
	24	31 (7)	0
	25	17 (7)	0
	26	25 (2)	0
Nearshore Stations	8	57 (2)	0
	14	14 (5)	20
	16	47 (4)	0
	17	17 (5)	25
	32	13 (4)	0
	33	29 (5)	0
	34	280 (6)	67
Marine Water Class B Standard		<100	<10

of bacteria were similar to those found in the ITT discharge on the same day (Table 2). This implies that the impact from the discharge is still directly measurable 150 feet from the source. Stations #34, 14, and 17 were the only nearshore stations that did not meet Class B water quality standards for FC bacteria (Table 4).

Outer harbor stations, #21 through 26, comprise a sampling transect originally set up by DSHS. The data (Table 4) indicate the Class B water quality standard has been met during Ecology's study. Results from surveys conducted by DSHS during March and April have also indicated that bacteria concentrations were low, often below detectable limits (G. Plews, personal communication).

Quality Assurance

Results from analysis of replicate samples analyzed by Ecology (MF) and DSHS (MPN) are given in Table 5. As expected, MPN results were somewhat greater. In either case the outer harbor would have met the criterion for Class B marine water. Since the MPN test is required by FDA for determination of sanitary quality, and since this is the more stringent test, it is necessary and appropriate for DSHS to use. The MF test is less expensive, used by EPA, and adequate for making water quality determinations. The variations between the methods should be kept in mind when comparing different studies.

Table 5. Comparison of replicate samples collected on March 18, 1987, and analyzed for fecal coliform bacteria using two different analytical techniques.

Station	MPN	MF
21	8	2
22	70	7
23	49	10
24	22	12
25	14	<4
26	49	18
32	240	28
33	79	6

MPN: Analyzed by the DSHS Seattle lab using A-1 Scratch media.
MF: Analyzed by the Ecology Manchester lab using MSC media.

Table 6 compares results from replicate samples tested by Ecology's Manchester laboratory and a private Seattle laboratory hired by ITT Rayonier. There is fairly good agreement between the laboratory results, even at the high concentrations measured. The only replicates with large differences in FC concentrations were those collected on April 15 and May 11. The samples collected on April 15 were not collected at the same time and therefore do not represent true replicates. The private lab results from May 11 are also questionable (E. Tokar, personal communication). Both ITT Rayonier and Ecology have been satisfied with comparisons of results from the different laboratories, and sample splitting has been discontinued.

Table 6. Comparison of replicate samples collected from ITT Rayonier effluent and analyzed by Ecology's Manchester lab and a private Seattle lab.

Date	Ecology	Private
March 18	22,000	22,000
March 31	27,000/41,000*	14,000
April 15**	36,500	2,500
April 28	10,000	3,000/10,000*
May 11	8,700/9000*	960/970*

*Replicate samples.
**Samples collected on the same day but not at the same time.

Fecal Coliform Bacteria as Indicators of Health Hazards

The use of FC bacteria as a standard was adopted in 1976 (EPA, 1976). This group of bacteria was thought to relate more directly to pathogens associated with warm-blooded animals than a measure of total coliform bacteria which was the standard previously in use. The FC group is primarily composed of *Escherichia coli* and *Klebsiella* spp. The *E. coli* is normally an intestinal organism associated with human fecal waste. *Klebsiella*, apparently a more ubiquitous organism, is also found in some industrial wastes, soil, water, and vegetation. The fact that *Klebsiella* is not considered a true indicator of fecal waste (although it is associated with human pathogens) has resulted in some controversy over its inclusion in a test to determine a waters sanitation.

This issue has arisen with the ITT discharge. The bacteria associated with this discharge are almost entirely *Klebsiella*. It is argued that these bacteria do not represent the health risk that other FC bacteria do, and therefore the standard for their control should not be the same. The FDA is responsible for setting sanitation standards for commercial shellfish production, and it does not distinguish between different FC groups. It is therefore essential that DSHS and Ecology regulate water quality in marine waters based on total FC bacteria to ensure protection of beneficial uses; e.g., commercial shellfish harvest.

Comparison of Bacteria Loading Sources

Figure 6 depicts the proportion of the bacteria load that can be attributed to each of the major inner harbor sources during different weather conditions. The relative size of the four circles represents the total bacteria loading present for the cases examined. Data used in preparing the figure are given in Table 7. No estimate is included for Simpson's discharges. Initially, these discharges were considered to be important contributors, but in the final analysis, the combined loading from pipes #7, 10, and 13 account for less than one percent of the total load to the harbor. An estimate of pipe #15's contribution is not possible due to the lack of flow data. Although concentrations are sometimes high (Table 2), the flow is presumably low since it carries only stormwater. Consequently, the overall contribution would still be small.

Drier Weather

Figure 6A represents conditions on April 15 after a moderate rainfall event. Figure 6B represents conditions on April 28 after a period of nine days of warm, dry weather. By comparing two consecutive sampling dates many of the changes that can be attributed to watershed characteristics (soil saturation and streamflow) are minimized. Therefore, the measured changes are assumed to be a function of the increased rainfall. As shown in

Table 7. Data used to calculate proportional loadings of the four major FC sources to the inner harbor.

Source	Fecal Coliform (#/100 mL)	Flow (cfs)	Loading (#/day)	Percent of Total Load	Fecal Coliform (#/100 mL)	Flow (cfs)	Loading (#/day)	Percent of Total Load
	April 15				April 28			
ITT Rayonier	36,500	0.54	4.8E+10	60	10,000	0.49	1.2E+10	80
Stormwater	1,200	2.16	6.3E+09	8	180	1.44	6.3E+10	4
Shelton	230	11.03	6.2E+09	8	26	7.92	5.0E+08	3
Goldsborough	44	184.00	2.0E+10	25	7	108.40	1.9E+09	13
	May 27				Extreme Wet Weather Load			
ITT Rayonier	18,300	1.03	4.6E+10	97	34,000	0.63	5.2E+10	9
Stormwater	9	0.80	1.8E+07	0	56,000	2.16	2.9E+11	48
Shelton	20	6.53	3.2E+08	1	2,500	21.80	1.3E+11	21
Goldsborough	6	63.31	9.3E+08	2	43	1158	1.3E+11	21

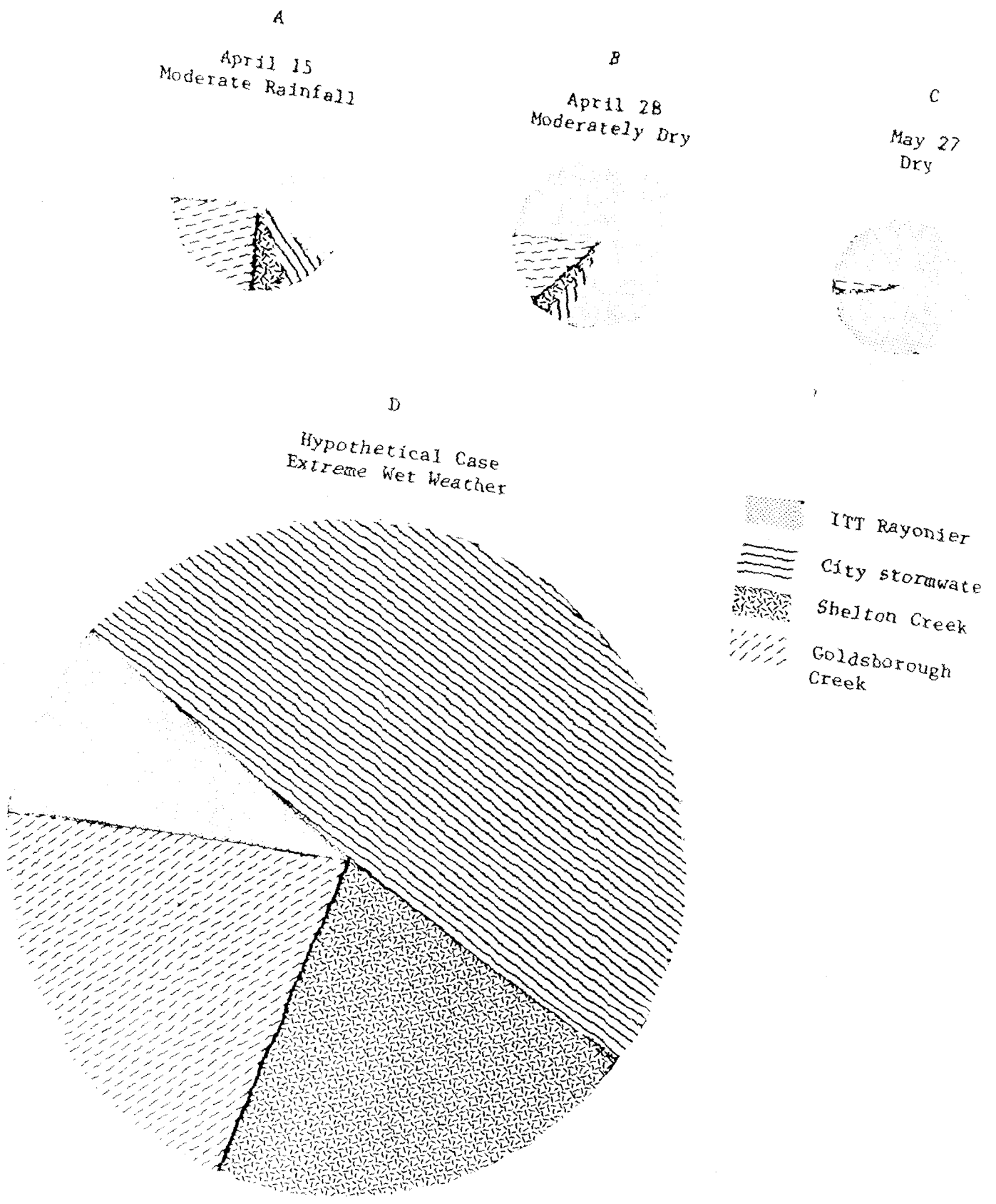


Figure 6. Comparison of contributions from bacteria loading sources during different weather conditions.

the Figure, the contribution by the ITT discharge accounts for the majority of loading in both cases. Goldsborough Creek is the second largest contributor. As mentioned previously, high flow in Goldsborough Creek compared to other inputs overshadows the low concentrations measured. Since the creek meets water quality standards, the load is acceptable. The City stormwater discharge and Shelton Creek both account for about the same proportion of the total loading. As expected, their contribution was higher on April 15 after a rain event. Although there were some differences between contributions by the individual sources, essentially the pattern and magnitude of loading was the same on both days.

Figure 6C represents more extreme dry-weather conditions. The May 27 sampling followed a long period of warm, drier weather, as proven by the much lower creek and stormwater flows. (Although these flows should continue to decrease during the summer, this is probably representative of typical dry-season loadings.) Both the bacteria concentration and flow decrease in the creeks and stormwater during the dry season. Consequently, a large decrease is seen in both the total load of bacteria and individual contributions. The ITT discharge is the only important loading source remaining.

Comparison of Figures 6A through 6C illustrates the relative importance of each of the sources during moderately dry to dry weather that Washington experiences for most of the year. The inner harbor met water quality standards on each of these days.

Wet Weather

Figure 6D represents a hypothetical case of loading contributions during a heavy rainfall when the watershed is saturated and the creek and storm drains are running high. These conditions would occur during winter months. The data are from field measurements taken during the investigation. An average load was used for the ITT discharge since it is not expected to change significantly during wet weather. The bacteria concentration used to estimate City stormwater loading was from a sample collected during sewage overflows. No flow measurement of the stormwater was possible on that day, so the highest measured flow from the study was used. (This may greatly underestimate loading since the added sewage flow during overflowing conditions is probably quite large). As expected, Figure 6D indicates that during extreme wet-weather conditions there is a dramatic increase in bacteria loading. City stormwater is the major loading source to the inner harbor, followed by Goldsborough and Shelton Creeks. During these periods, the ITT discharge is the smallest significant source. Figure 6D represents conditions that would likely lead to Oakland Bay water quality violations.

Seasonal Impact on Water Quality

The 1986-87 (DSHS, 1987) survey report hypothesized that high bacteria concentrations measured in Oakland Bay were likely due to a point source. This conclusion was drawn from the following:

- The surveys occurred during periods of little or no rainfall.
- The highest counts observed were close to the inner harbor area where point source discharges were most likely.
- Stream samples had fairly low bacteria concentrations.

Past surveys done by DSHS in 1979 and 1984 indicated Oakland Bay waters were clean and met the FC bacteria standard. Thus it was concluded that some change had taken place since the earlier surveys.

Table 8 contains DSHS survey results from 1979, 1984, and 1986-7. Because all of these surveys had occurred during periods of little or no rain, they were considered to represent similar, dry weather runoff conditions. Yet, hydraulic conditions and watershed soil characteristics are typically much different in December and January (1986-7 survey) than during April/May or October (1984 surveys). During winter when the Oakland Bay drainage receives most of its rain, the soils are often saturated for long periods of time and runoff may occur for extended periods. Consequently, even in the absence of rain, runoff may still be affecting water quality. This situation may be exacerbated in estuaries and embayments such as Oakland Bay where flushing may be poor.

The antecedent precipitation index was used in an effort to assess the differences in watershed moisture conditions between survey periods. The index was calculated using precipitation data for the 14 days preceding the first day of sampling and the equations (after Linsley Kohler, and Paulhus, 1975):

For I_1 to I_{15}:

$$I_1 = P_1$$
$$I_2 = I_1(k) + P_2$$
$$I_3 = I_2(k) + P_3$$
$$\vdots$$
$$I_{15} = I_{14}(k) + P_{15}$$

where:

I = Antecedent Precipitation Index (API)
I_1 = API 14 days before the first day of sampling
I_{15} = API on first day of sampling
k = Recession factor for evaporation (Range: 0.85-0.98)
P_1 = Precipitation 14 days before the first day of sampling

Table 8. Comparison of DSHS water quality studies in Oakland Bay. All values are in FC/100 mL, and were analyzed using the MPN technique (DSHS, 1987).

	August 1979		April-May 1984		October 1984		Dec./Jan. 1986-87	
Station	Geometric Mean	Percent >43	Geometric Mean	Percent >43	Geometric Mean	Percent >43	Geometric Mean	Percent >43
10	4	7	23	38	3	0	15	14
7	5	0	8	0	8	7	18	14
12	10	7	15	38	4	0	26	36
6	4	7	23	25	6	0	16	7
8	11	0	10	13			36	50
5	18	13	9	0	5	7	30	36
9	7	7	7	0	6	0	22	29
11	12	13	4	0	9	21	30	57
4	13	20	17	43	13	14	48	57
3	77	67	22	13	30	43	155	95
15			13	0			47	64

Stations above the dotted line are located in the "Conditionally Approved" area, while stations below the dotted line are in the "Prohibited" area of the bay.

A "k" value of 0.98 was used for December and January sampling events when evaporation would be minimal due to cool temperatures and cloud cover typical of that season. A value of 0.85 was used for August sampling when evaporation is expected to be highest. And a medium (but conservative) value of 0.88 was used for the April, May, and October sampling dates. The calculated values for the DSHS survey dates and some of the survey dates from this investigation are:

Date	API (inches)
August 23, 1979	0.66
April 30, 1984	0.38
October 23, 1984	0.77
December 2, 1986	10.75
January 5, 1987	5.94
April 15, 1987	1.61
April 28, 1987	0.33
May 27, 1987	0.08

Although this is a rough "index" of watershed moisture conditions, the extreme values calculated for December and January as compared to other sampling dates, indicate conditions were different during the December and January surveys. The watershed would have been saturated, and runoff would have remained high. Sanitary, storm, and septic system overloads likely would have continued to occur.

Thus, although the December/January DSHS samples were collected during days of lower precipitation, the watershed conditions were likely inducing continued non-point pollutant loading to the Oakland Bay. Samples collected from the Bay by both DSHS and Ecology during the spring sampling had very low FC concentrations. This strongly supports the theory that the high bacteria concentrations measured during December and January of 1986-7 by DSHS were generated by increased runoff and saturated soil conditions, rather than a recent increase in loading from a point source.

CONCLUSIONS

The primary objectives of the study were to determine the important sources of fecal coliform bacteria to the inner harbor, and to determine whether the high bacteria concentrations were related to wet weather.

The major loading sources have been identified:

- City of Shelton stormwater
- ITT Rayonier effluent
- Shelton and Goldsborough Creeks

The relative contribution of these sources varies with season. ITT is the largest loading source except during periods of high runoff when Shelton stormwater is estimated to dominate.

Probably the most important source is the City stormwater discharge. It appears to account for only a small portion of the loading during most of the year, but during the critical wet-weather period, it can become the major contributor of bacteria.

Goldsborough Creek has been estimated to represent a significant portion of the load through most of the year. Yet is not considered as an important source (i.e., a place to concentrate further investigation/control efforts). Bacteria concentrations are low, within standards, and within normal background levels. Therefore, it is unlikely that improvements to the creek or its watershed would result in significant changes in bacteria loadings.

Conversely, Shelton Creek is considered to be an important source even though it represents only a small percentage of the total loading. The high concentrations measured in the creek indicate the[illegible] unknown sources of bacteria. These may become even more i[illegible] during the wet season.

Other sources such as Simpson stormwater runoff, and miscellaneous pipes and septic systems may also be more important during wet weather.

Steps have already been taken to control ITT's effluent and the City stormwater problem. In the latter case, long-term solutions will require several years to put into effect. Shelton Creek needs further study to determine which segments of the stream are contributing the bacteria load and the sources (e.g. septic system, animal waste, or urban runoff). No plans have been made for corrections to Goldsborough Creek since it does not appear to be a problem. It is possible that further wet-weather sampling will not support this view, in which case a plan for study or control of the sources may be necessary.

The information collected to date indicate the bacteria pollution problem is a seasonal phenomenon related to non-point pollution sources. Most of the sources examined (City stormwater, industrial site runoff, and the two creeks) can be expected to be heavily impacted by rain events and to some extent this was observed.

A possible explanation for the Oakland Bay situation is that the ITT discharge is contributing a large, constant source of bacteria to the inner harbor, but its impact alone is not great enough to cause significant water quality problems. During winter, additional loading occurs from non-point sources. The cumulative impact is apparently enough to cause water quality violations.

RECOMMENDATIONS

- Continue monitoring all sources during wet weather to define the importance of their respective contributions during this critical period.

- Control city of Shelton sewage collection system problems.
- Determine the effectiveness of lowering pH as a means of controlling bacteria concentrations in ITT Rayonier's effluent.
- Change ITT Rayonier permit to reflect a fecal coliform concentration limit and monitoring requirements.
- Determine the impact of industrial site stormwater runoff on water quality.
- Further investigate sources of bacteria to Shelton Creek and the impact of the unsewered area on creek water quality.

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