FINAL REPORT

Factors affecting nonpoint source fecal coliform levels in Quilcene and Dabob watersheds, Jefferson County, Washington.

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>BACKGROUND AND STUDY AREA</td>
<td>2</td>
</tr>
<tr>
<td>METHODS</td>
<td>5</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>9</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>21</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>22</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>23</td>
</tr>
</tbody>
</table>
INTRODUCTION

The Jefferson County Planning Department conducted water quality monitoring in marine waters and freshwater streams feeding Quilcene and Dabob Bay from 1986 through 1989. This work was conducted under contract to the Washington Department of Ecology. Results of some of this monitoring work including descriptions of the watersheds and identification of some of the sources of the freshwater contamination has already been reported (Welch and Banks 1987, Banks et al. 1987). These previous reports also included a summary of the results of the water quality monitoring completed through mid-1987.

This report summarizes statistical analysis of the water quality data for Quilcene and Dabob Bay and the results of the monitoring effort from 1986 though 1989.
BACKGROUND AND STUDY AREA

Background

Elevated levels of fecal coliform in shellfish growing waters have been documented in northern Hood Canal. Portions of both the Duckabush River tidelands and the Dosewallips River Delta (south of Quilcene Bay) have failed to meet the water quality standards and have been reclassified to a lower level (DSHS 1988, 1989a). In Quilcene Bay a 204-acre section at the north end of the bay has recently been downgraded and reclassified as prohibited (Cook 1984, 1985). This area includes the tidelands north of the mouth of the Big Quilcene River on the west shore to the southern end of the log dump on the eastern shore (Cook 1984). This area has not been used for shellfish growing during the past 10 years because of the soft substrate. Although the closure has not caused a significant hardship to the operators, it still presents a concern about the source of the bacterial contamination and the fear that the contamination could spread beyond the current closure zone into productive shellfish grounds.

Causes of the contamination have been considered in some of the previous reports on contamination in this region. Cook (1984) states "Samples taken from the Little Quilcene River and Donovan Creek seem to point to these two tributaries as major contributors to bacteriological contamination of Quilcene Bay water." Banks et al. (1987) and Welch and Banks (1987) conclude that the marine contamination stemmed from a combination failing septic systems, contamination from domestic animals, and a local population of harbor seals. Calambokidis et al. (1987) concluded seals had the potential to be major contributors to the contamination in Quilcene Bay. In subsequent studies, harbor seals were found to be the major contributors to contamination in other areas including the Dosewallips Delta (DSHS 1989a, Calambokidis et al. 1989), but not the likely major contributors in Quilcene Bay (Calambokidis et al. 1989).

Bacterial levels in nearby Dabob Bay have been reported to be lower than in Quilcene Bay. Results from Cleland (1984) indicate that Dabob Bay continues to meet water quality standards for approved shellfish growing areas and may be better than standards for much of the time. The study warns that recreational and commercial boating, failing septic systems and livestock waste are believed to be major threats to water quality in the bay.

For the past 3 1/2 years, the Jefferson County Planning Department has been the lead agency in conducting nonpoint source water quality projects. Funding for the monitoring research was provided through the Washington State Department of Ecology.

Additionally, the department also informs citizens of the WATERSHED ABOUT WATER QUALITY CONDITIONS and will administer the recently adopted Quilcene/Dabob Bays Watershed Action Plan. The
priorities have been directed toward monitoring the levels of fecal coliform bacteria in both fresh and marine water in the Quilcene and Dabob watersheds for shellfish protection, and advocating voluntary cooperation for corrective action where water quality degradation occurs. The Planning Department does not, however, enforce, regulate, or engage in the compliance process for violators to conform to the state water quality standards.

Study Area

Welch and Banks (1987) review major features of Quilcene Bay. These are summarized below for areas relevant to this study.

Setting: Quilcene Bay has five growers on the 918 acres producing clams/oysters. Quilcene Bay is classified as AA waters and most of the bay is Approved for commercial shellfish harvest. At the North end of the bay, however, a 204 acre area is classified as prohibited. No commercial shellfish activity may take place in prohibited areas (DSHS 1989b). Dabob Bay, also classified as AA, has eight growers on 5,895 acres approved for commercial shellfish harvest of clams/oysters (DSHS 1989b).

Climate: The region enjoys a maritime climate characterized by short dry summers and long cool, wet winters. Ambient temperatures are generally in the 70's (F) with winter time lows in the 30's.

Geology and Soil: The geology of the area includes tertiary basalt bedrock, sandstone and shale along south and west boundaries of the Little Quilcene and Donovan Creek and along the west side of Tarboo Valley. Throughout much of the Toandos Peninsula, glacial outwash and till were deposited from the Frazier glaciation 10-20,000 years ago. The glaciers had a thickness of as much as 300 feet and the great weight compressed the glacial till into compact, weakly cemented material that covers much of the area that is present in the project area today. This "hardpan" is found at depths from 10 to 40 inches and acts as a barrier to water absorption. Because of this, there are several areas where the soils are poorly suited for on-site sewage disposal and animal keeping.

Marine mammal: Harbor seals are the most abundant marine mammal occurring in Quilcene and Dabob Bays as well as the rest of Puget Sound and Hood Canal. Harbor seals were hunted and killed under a bounty paid by Washington State up until the early 1960s because of purported predation on commercially valuable fish. In the early 1970s both the state and the federal government enacted legislation protecting harbor seals and other marine mammals. Since the 1970s harbor seal populations have been increasing throughout Washington State at a rate of 5-15% per year (Calambokidis et al. 1987).
Harbor seals use land areas where they rest and give birth to young. In Quilcene Bay, harbor seals use log-booms, floats, and oyster rafts for this purpose. A maximum of 403 harbor seals has been counted inside Quilcene Bay at any one time (Calambokidis et al. 1989).

**Land use:** The drainage areas for the streams feeding Quilcene and Dabob Bay is generally sparsely populated except for approximately 600 residents of the town of Quilcene. Most of the project area is forested with many areas of small-scale agriculture. Identified sources of fecal coliform contamination in the area include failing septic systems and livestock production (Welch and Banks 1987).

**Water Quality Standards:** The water quality standards set forth in WAC 173-201 are established in conformance with present and potential uses of the surface waters. Beneficial uses for fresh and marine waters are described in the water quality standards for waters of the state of Washington (chapter 173-201, WAC). These uses include supplies for domestic, or agriculture purposes; fish, shellfish, and wildlife habitat; recreation and navigation.

For fecal coliform bacteria, the state standard is as follows:

**CLASS AA (extraordinary) water:**
Freshwater: fecal coliform organisms shall not exceed a geometric mean value of 50 organisms/100 ml, with not more than 10 percent of the samples exceeding 100 organisms/100 ml.

Marine water: fecal coliform organisms shall not exceed a geometric mean value of 14 organisms/100 ml, with not more than 10 percent of the samples exceeding 43 organisms/100 ml.
METHODS

Freshwater Sampling

For the Quilcene watershed, thirteen stations were established along the four major freshwater sources feeding Quilcene Bay and four stations on the major creek feeding Dabob Bay (Figure 1). On all streams, stations were established to bracket land use (Kittrell 1969). "Headwater" stations acted as a control and were the highest station on the stream. Unfortunately, some of the "headwater" stations were located below a home or pasture because the land owners on the stream did not allow access to their property.

With minor exceptions, stations were as described in the phases one report (Walch and Banks 1987). A station was added at the south end of Lake Leland (LL0) and one deleted (LL2) at the beginning of phase two of the study. The rationale for the alteration in the Leland sampling was to help determine if any degradation occurred in the pasture land between the lake outlet and station LL1. Other factors affecting sampling included low water flows that prevented sampling along Cemetery Drain during portions of each year, and the interruption of sampling at some stations because of problems obtaining the permission of some landowners.

Freshwater samples were taken in sterile 125 ml Nalgene bottles at the surface. Sampling was conducted on streams feeding Quilcene Bay from 17 June 1986 to 14 February 1989. Streams were usually sampled one day each month though multiple samplings were conducted in some months. Freshwater samples were generally collected before the monthly collection of marine water samples.

Stream flows were measured with a Marsh-McBirney water current meter Model 201-D and were taken at the lowest station on each stream and major tributary. Stream flow was calculated by measuring water velocity at several points a section of the stream. The formula used for computation was:

\[ Q = \text{sum}(av) \]

Where \( Q \) is the total flow (cubic feet per second), \( a \) is an individual subsection area \( (\text{cm}^2) \), and \( v \) is the corresponding mean velocity of the flow of a subsection in feet per second (Rantz 1982).

Loading was calculated using the following equation (Kittrell, 1969):

\[ \text{fc loading (billions per day)} = \text{fc} \times Q \times 0.0246 \]

where: fc is the fecal coliform count per 100 ml and \( Q \) is the stream flow (cfs).
Figure 1. Locations of freshwater and marine sampling stations in Quilcene and Dabob Bays (from Welch and Banks 1987).
Rainfall calculations

For each sampling day, rainfall totals for the four days previous to collection were calculated. The daily rainfall data were provided by the Quilcene District of the US Forest Service.

Rainfall levels, together with bacterial concentration and loading levels, were used as an identification tool to determine whether the source of fecal coliform contamination was related to land use practices or had a marine water origin. Previous studies have shown that bacterial concentrations in streams tend to increase with rainfall (Determan 1985).

Marine Water Sampling

Marine water sampling was conducted monthly starting in June 1986 and ending in February 1989. There were five marine stations monitored in Quilcene Bay and four in Dabob Bay (Figure 1). Stations 3 and 4 in Dabob Bay were not monitored during the second phases of this study because of the historically low FC concentrations values. Stations were generally located close to the creek/river mouth given the constraints of tide and water depth. Other stations were centrally located in the bays enabling us to assess the effect of freshwater loading.

Surface water (top 3 inches) samples were collected from a Boston Whaler in sterile 125 mL Nalgen sample bottles and stored in a cooler on freezer packs until laboratory procedure started. Collection time was as near to the high ebb tide as possible. At the time of collection, surface salinity and temperature were taken using a Beckman Salinometer Model RS5-3.

Sample analysis

Water samples were collected, labeled and the stored in a cooler on freezer packs. Laboratory analysis of the samples was usually initiated within 6 hours of collection, and never more than 24 hours after collection.

All freshwater samples were analyzed for fecal coliform using the membrane filtration technique with MFC dehydrated media. Marine water was analyzed by the Most Probable Number (MPN) technique using a five tube decimal dilution series and A-1 media (Franson, 1980). Analysis of marine water prior to January 1, 1988 was conducted by the county in a laboratory set up for the study. Samples analyzed from January 1988 through February 1989 were conducted at the Washington State Public Health laboratory in Seattle, Washington.

Water quality data was recorded directly on laboratory sheets in the field. Supplemental information was recorded in field note books.
Data analysis

Before data analysis, data values were error checked. Phase one values were taken at face value from the Welch and Banks (1987) report because the original data had been lost. In cases where zero was recorded in their report we reassigned the minimum detection limit of 1.8. For phase two, a complete data audit was conducted on all values.

A number of statistical analyses were conducted to test for significant associations in the data. These included:

Linear regression was used to test whether one variable, such as marine water quality, varied in response to a one or more factors, such as rainfall or salinity.

Paired t-tests were used to test for significant differences between two stations on a stream. This test compares paired values (each day) to determine if one consistently is higher or lower than the other.

Statistical tests were conducted using SYSTAT (Wilkinson 1988). All concentrations and loading values were log transformed for statistical tests. Geometric means of concentrations were computed by retransforming the mean of the log transformed values.
RESULTS AND DISCUSSION

Freshwater concentrations and loadings

Streams feeding Quilcene Bay

Fecal coliform concentrations varied dramatically among the 15 stations along five streams feeding Quilcene Bay (Figure 2, Table 1). Highest mean concentrations were seen near the mouth of Cemetery Drain and Donovan Creek. All the stations on Cemetery Drain and Donovan Creek failed one or both of the criteria for Class AA waters (which is their current status). Additionally Station 1 on Leland Creek also failed one of the criteria for Class AA waters. In contrast, stations on the Big Quilcene and Little Quilcene River met the Class AA requirements.

Several streams had significant trends in water quality at different stations, generally reflecting a trend of increasing concentrations downstream. A significant increasing trend was observed on the Little Quilcene River between stations 1 and 3 (n=33, p=0.01) and between stations 2 and 3 (n=34, p=0.001); Cemetery Drain between stations 1 and 3 (n=21, p=0.000) and between stations 2 and 3 (n=18, p=0.004); and on Donovan Creek between stations 1 and 2 (n=32, p=0.000). These trends indicate more contaminated inputs are occurring downstream as compared to upstream along these rivers. For the Little Quilcene River, the higher concentration at station 3 appears to at least partly be the result of the input from Leland Creek that had a higher concentration that the upstream stations on the Little Quilcene. An exception to the above trends occurred on Leland Creek where concentrations decreased significantly between stations 1 and 3 (n=32, p=0.04).

Concentrations at different freshwater stations feeding Quilcene Bay varied significantly with date. Four stations appeared to show an improvement in fecal coliform concentrations over time: Big Quilcene Sta. 1 (n=13, r=0.57, p=0.04), Cemetery Drain Sta. 3 (n=24, r=0.56, p=0.02, Figure 3), Leland Sta. 0 (n=19, r=0.45, p=0.05), and Leland Sta. 2 (n=15, r=0.58, p=0.025). These results should be viewed very cautiously, however, because three of these four sites were only sampled for half the study. On Leland Creek, sampling at station 2 was discontinued half-way through the monitoring program to allow sampling at a new site upstream (station 0). Monitoring over a longer period will be required to detect trends in contaminant concentrations accurately.

Rainfall also significantly affected the fecal coliform concentrations at some stream stations though not always in the same way. Bacterial concentrations tended to decrease after heavier rains at Cemetery Drain Stations 1 and 3 (p=0.01 and p=0.04, respectively, Figure 4) but tended to increase after rains at Leland station 3 (p=0.05). Fecal coliform concentrations at other stations not mentioned above, showed no statistically significant relationships with date or rainfall.
Figure 2. Geometric mean fecal coliform levels for freshwater stations feeding Quilcene and Dabob Bays. Numbers above bars indicate number of samples and vertical bars show 95% confidence interval.
Table 1. Concentrations, flow rates, and loadings of fecal coliforms in streams.

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11
Figure 3. Association between freshwater concentration and collection date at Cemetery Drain Station 3.
Figure 4. Association between freshwater concentrations and rainfall at Cemetery Drain Station 1.
Little Quilcene River and Donovan Creek contributed the highest proportion of fecal coliforms to Quilcene Bay (Figure 5, Table 1). Stream loading was examined in two ways. First, the geometric mean loading was calculated for each stream and these are given in Table 1. Second, the average proportion contributed by each stream to the total loading for all streams was calculated for the days when data from all streams were available. This latter indicator relies on a smaller sample because it excludes days when either loading or fecal coliform concentration was not available for any stream. Though the magnitude contributed by each stream varied somewhat, both methods showed the same pattern.

Fecal coliform loading (a function of fecal coliform concentration and stream flow) increased with higher rainfall. This was the direct result of the association between rainfall and stream flow (Figure 6). Fecal coliform loading increased significantly with increasing 4-day rainfall for the Big Quilcene River (n=32, r=0.48, p=0.006), Little Quilcene River (n=35, r=0.40, p=0.02), Cemetery Drain (n=21, r=0.65, p=0.001), and Leland Creek (n=32, r=0.84, p=0.000). Loading from Donovan Creek was not as strongly associated with rainfall; the relationship fell just short of statistical significance (n=30, r=0.34, p=0.07).

No improvement in loading from the different streams was noted over the course of the study even taking into account the influence of changing rainfall. A lack of improvement in loading over time indicates that a longer time period or additional remedial action will be required to create a detectable improvement in water quality. This suggests the possible improvements in water quality mentioned previously for a few stations were likely sampling artifacts.

Streams feeding Dabob Bay

The three stations along Tarboo Creek and single station on Coyle Creek all had very high concentrations of fecal coliforms (Table 1) that failed one or both of the criteria for Class AA waters. Concentrations were highest at the two downstream stations on Tarboo Creek. Significant increases in fecal coliform concentrations were noted between station 1 and both stations 2 and 3 downstream on Tarboo Creek (paired t-test on log values, p<.000 for both cases). There was no significant difference between stations 2 and 3 (n=35, p=0.16). Concentrations near the mouth of Tarboo Creek (above the input from Coyle Creek) were also significantly higher than at the mouth of Coyle Creek (n=34, p=0.000).

Concentrations at some of the stream stations showed improvement over the study. Also, fecal coliform concentrations (log transformed) at both station 2 on Tarboo Creek (n=36, p<0.007) and the mouth of Coyle Creek (n=34, p=0.02) showed a significant decrease with rainfall. Station 1 on Tarboo Creek showed a significant improvement over the length of the study.
Figure 5. Mean fecal coliform loadings for streams feeding Quilcene Bay. Vertical bars show 95% confidence intervals and numbers show sample size.
Figure 6. Association between loading and rainfall in Big Quilcene River.
(n=33, p=0.05) and this association was stronger if a marginally significant association with rainfall was also included in the model.

The geometric mean fecal coliform loading from Taraboo Creek was over 10 times higher than for Coyle; a significant difference (paired t-test, n=26, p=0.000). No significant associations were seen between loading at either stream and either date through study or rainfall in the previous four days. Average loading from Taraboo Creek was comparable to the loading from some of the streams feeding Quilcene Bay. But the total loading into Dabob Bay was less because of the lack of major contributions from other streams.

Marine concentrations

Quilcene Bay

Concentrations of fecal coliforms at the five marine stations in Quilcene Bay decreased from the head of Quilcene Bay south towards the mouth of the bay (Figure 7). None of the marine stations fail the first part of the regulatory standard for a shellfish growing area and only station 1 at the head of the bay fails the second part of the standard. Previous surveys conducted by the Shellfish Section of the Department of Social and Health Services (currently Department of Health) found values that failed the standard in the northern part of the bay including the area around station 2 (Cook 1984).

Loading from the Big Quilcene River was the most consistent factor affecting the marine concentrations. Concentrations at all five marine stations were significant correlated with loading from the Big Quilcene River (p<0.01 at four stations and p<0.05 at one station). This analysis only included days when stream loading was available for a period within two days of when the marine concentrations were taken.

Additionally, the linear regression analysis of the marine concentrations revealed significant associations with salinity, and rainfall. Concentrations were significantly negatively correlated with salinity at three of the five stations (2, 4, and 5). Concentrations at station 5 were significantly associated with rainfall (n=31, r=0.52, p=0.003). Statistical tests of concentrations at station 5, however, should be viewed cautiously because of the high proportion of values that fell below detection limits. These detection limit values pose a problem for statistical analysis because they are not true measurements yet cannot be ignored without biasing the data.

The significant associations with salinity, rainfall and stream loading are all related since these factors are all intercorrelated with each other. Salinity at four of the five marine sites was significantly associated with either rainfall or stream flow from the Big Quilcene River (step-wise and multiple regression tests, p<0.05 in all four cases). At stations 1 and 2
Figure 7. Geometric mean fecal coliform concentrations at marine concentrations in Quilcene and Dabob Bays.
multiple regressions of the combined effects of salinity, loadings from the Big Quilcene River, and/or rainfall provided a better regression than any of the factors singly. These findings indicated elevated marine concentrations tended to occur after periods of high stream loadings and low salinities. This was consistent with a freshwater source being responsible for the elevated bacterial concentrations in Quilcene Bay.

Other factors were not significantly associated with fecal coliform concentrations at the marine stations. These factors included sampling date, water temperature, tide patterns, and loading from streams other than the Big Quilcene. The lack of association with loading from other streams beside the Big Quilcene is difficult to explain, because this stream did not have the highest mean loading into Quilcene Bay.

The potential relationship between tidal patterns and concentrations was examined to test the hypothesis that some of the contamination resulted from tidal flooding of areas used for keeping domestic animals. If this was the case then marine samples taken after higher high tide would be expected to have higher concentrations. No association was found between concentrations at marine stations and the height of the previous high tide (p>0.05).

We found no evidence that harbor seals were responsible for the elevated concentrations of fecal coliforms in Quilcene Bay. Stations closest to harbor seal haul-out areas are station 2 (40 m from the log booms used by the largest number of seals) and station 5 (750 m from the oyster rafts occasionally used by seals). Other areas of the bay are used by seals for sleeping in the water, feeding, and transit. These areas, however, appear to be used by fewer animals for shorter periods than the haul-out areas. Research at Still Harbor and the Dosewallips Delta suggested elevated concentrations of fecal coliforms were closely associated with the haul-out area (Calambokidis et al. 1989, DSHS 1989a). This was not the case in Quilcene Bay.

Since seal numbers at the haul-out area varied daily, we also tested for a relationship between marine concentrations and numbers seals counted during that same time period. Since seal counts were not conducted in coordination with water quality sampling, only 13 samples were available with both water quality and seal counts within a week of each other. No relationship was found between concentrations and seal numbers from this limited dataset (p>0.05 in all cases).

Dabob Bay

Fecal coliform concentrations in Dabob were generally lower than in Quilcene Bay. All stations were under both parts of the criteria for approved commercial shellfish harvest. Data was limited for stations 3 and 4 because these sites were only sampled during the first half of the study. Concentrations at all stations except station 1 had values below the minimum
detection level of 1.8 fecal coliforms per 100 ml on 80% or more of the sample days. At station 1 elevated concentrations of over 100 fecal coliforms per 100 ml were noted on only one day, following 7.4 inches of rain in the previous 4 days, the highest level of rain preceding any other sampling period.

Marine concentrations at station 1 were significantly associated with both rainfall and loading from Coyle Creek, though these statistical tests are compromised by the number of values below detection limits. Statistical examination of marine values at the other stations in Dabob Bay could not reliably be made because of the high proportion of values below detection limits.
CONCLUSIONS

Some of the major conclusions from the analysis of the monitoring data include:

Bacterial contamination in streams feeding Quilcene and Dabob Bays were high and exceeded those mandated for these streams (Class AA designation).

Concentrations of fecal coliform in freshwater generally deteriorated with distance downstream.

Marine stations at the north end of Quilcene Bay show the highest bacterial concentrations but did not fail the Washington State water quality standards for shellfish growing if the data for the entire monitoring effort are pooled.

Though harbor seals were likely contributors to the fecal coliform levels, the relationship between Quilcene marine concentrations and the amount of rainfall, salinity, and loading of some streams indicated that contamination from upland sources (humans and domestic animals) were probably the principal cause for the marine contamination.
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