

**Appendix A**  
**Circulation Study**

## APPENDIX TO SOUTH HENDERSON INLET SANITARY SURVEY: DRAFT HYDROGRAPHIC STUDIES NEAR STATION #5

### INTRODUCTION

From December 1999 through February 2000 the Department of Health (DOH) and the Thurston County Environmental Health Program (TCEH) conducted a series of hydrographic studies to help determine the source of pollution at Station #5 in south Henderson Inlet. This effort was prompted by the failure of Station #5 to meet the water quality standards for its shellfish classification. At the time of this report, shellfish harvesting in the area is closed when 0.5 inch or more of rainfall occurs within a 24-hour period. Identification of the general pollution source area(s) would be needed prior to remediation efforts, and to demonstrate the need for subsequent survey efforts in the identified watershed(s).

Prior to the hydrographic studies, an analysis of recent water quality data at Station #5 indicated three significant findings:

1. Most of the unsatisfactory water quality results occur during ebb tide cycles, and overall ebb tide water quality results are worse than samples collected on flood tides.
2. While rainfall is associated with many of the pollution events, several of the excessively high (i.e., greater than 43 FC/100 ml) fecal coliform results are obtained during relatively dry (< 0.5" rainfall in 24 hours) conditions.
3. Water quality at Stations 1 and 2, located to the south of Station #5 in the Prohibited area, is worse than at Station #5. However, the water quality at Station 3, located south and west of Station #5 in the Prohibited area, is better than at Station #5.

DOH and TCEH coordinated a series of studies in south Henderson Inlet to help explain the factors and reasons for these three findings.

### RESULTS OF INVESTIGATIVE STUDIES

#### DECEMBER 9

The first intensive investigation by DOH and TCEH occurred on December 9<sup>th</sup> on an ebb tide with a tidal range ("swing") of 7.5 feet. The Henderson Inlet Conditionally Approved area was open to harvest on that day. The previous rainfall event with greater than 0.5"/24 hours (0.92") occurred on December 2<sup>nd</sup>. A high tide of 14.9 feet was at 7:28 AM and a low tide of 7.4 feet was at 12:56 PM (tide chart is attached). Two sets of fecal coliform samples were collected at five locations to observe any differences in results during different stages of ebb tide within and just outside the cove at Station #5. The samples collected just outside the cove were taken about ten yards north and south of the western shoreline boundary of the cove.

The first set of samples, taken at the start of ebb tide, indicated that the fecal coliform level at Station #5 (46 FC/100 ml) was higher than that of either Creek B (north creek branch) or Creek C (south creek branch, see map) entering the cove. These results were 33 and 17 FC/100 ml, respectively. However the water quality at the south entrance to the cove (from the inlet) was greater than Station #5 (49 FC/100 ml). Water at the north entrance to the cove was 17 FC/100 ml).

A set of three drogues and three surface floats were released at the mouth of both Creek A and Creek B at the beginning of ebb tide to observe their movements into the main area of the cove. The surface floats indicate movement in the upper 2-3 inches of the water column, whereas the drogues indicated water movement a foot below the surface. Surprisingly, none of the drogues or floats moved into the main body of the cove throughout this study day, and instead remained near the creek mouths.

Drogues, surface floats and dye (fluoresceine) were released at the southern entrance of the cove at mid-ebb tide. While the relative speeds of these three indicators varied, all three of these indicators entered the cove and passed directly through or by Station #5. These results explain how the fecal coliform level at the south entrance to the cove could impact the water quality at Station #5, even on ebb tide. The surface floats, drogues and dye passed through the Station #5 area, headed directly towards the cove's north shore, and either got beached there or circled around the main area of the cove in a continuous clockwise pattern.

A second set of fecal coliform samples was collected towards the end of this ebb tide cycle. Water quality at the south entrance to the cove still had the highest count of the series (79 FC/100 ml). Station #5 results had dropped to 13 FC/100 ml, both creek mouths had a level of 33 FC/100 ml, and the area at the north cove entrance showed 34 FC/100 ml.

The results obtained during December 9 show that fecal coliform results at Station #5 can vary within a single tidal cycle. In addition, on this day, the highest source of pollution to the cove and Station #5 appeared to be entering the cove from the south, from Henderson Inlet. Finally, polluted water entering the cove can remain in the cove for long periods due to the clockwise gyre evidenced during this ebb tide cycle.

## DECEMBER 13

The second hydrographic study by DOH and TCEH occurred on December 13<sup>th</sup>, on an ebb tide with a range of 8.2 feet. The Henderson Inlet Conditionally Approved area was closed to harvest on that day, due to 1.26" of rain in the previous 24 hours. A high tide of 15.1 feet was at 9:55 AM and a low tide of 6.9 feet was at 4:08 PM (see attached tide chart). The main purpose of this investigation was to trace the flow of Woodland Creek through the south part of Henderson Inlet on a typical ebb tide. Drogues and floats were used as indicators of this flow. A 12-channel global positioning system (GPS) unit monitored their positions with time. In addition, a series of fecal coliform samples were collected within and just outside the cove at Station #5.

Prior to the drogue and float release, the cove at Station #5 was visited to observe if any of the eleven surface floats left in the cove from the December 9<sup>th</sup> study still remained (all drogues were retrieved at the end of the first study). Four surface floats still remained within the inner portion of the cove, again indicating that pollution can remain in the cove for long periods of time.

Surface floats and drogues were released at 10:17 AM at the southern end of Henderson Inlet, approximately 500 feet northwest of the Johnson Point Road bridge. The surface floats moved at a faster speed, but in the same direction as the drogues. On occasion the floats or drogues would get hung up on a branch or on a shoreline, at which time they would be retrieved and re-released nearby. The surface floats better represented the flow of Woodland Creek, as the salinity at the surface (3 ppt) was much less than at a one-foot depth (10 ppt) at the southern part of the inlet. At 10:58 AM the surface floats were 0.23 mile from the initial dropoff point, which is an average speed of 0.34 mph. This relatively slow speed may have been due to the release of drogues and

floats at the very start of ebb tide. The drogues did not arrive at this location until approximately 11:03 AM (average speed of 0.30 mph). The floats traveled 0.35 mile by 11:05 AM, but the drogues did not arrive at this approximate location until 11:28 AM. In order to not lose sight of the surface floats, the drogues were retrieved and placed near the surface floats.

At 11:15 the floats were near Dobbs Creek Cove. Surface salinity at this location was 11 ppt, and 22 ppt at a one-foot depth. At 11:30 AM the surface floats were due south of the mouth of the large unnamed cove, which faces to the south, at a distance of 0.58 mile to 0.63 mile from the release point (an average speed of 0.50 mph). At this location their trajectory abruptly but consistently changed from a northern direction to a WNW direction. The surface floats then all approached within 20-40 feet of the western shoreline for the next 0.3 mile. At 12:02 the floats had traveled 1.06 mile and started a trajectory directly for the Station #5 cove from the western shoreline. At this location the surface floats had achieved an overall average speed of 0.61 mph from their initial release location. The floats continued in a straight line until just south of the airplane runway, at which time the trajectory become parallel to the eastern shoreline. The floats passed west of Station #5 about 60 yards at 12:15. Therefore the surface floats traveled to the immediate area of Station #5 from the southern end of Henderson Inlet, a distance of 1.38 mile, in just less than two hours on a typical ebb tide. The average speed for their entire trip was 0.70 mph.

The path traveled by the surface floats is illustrated on the attached map. This route directly coincides with the streambed of Woodland Creek that meanders through Henderson Inlet. In addition, this route helps explain why the water quality at Station 3 is much better than at Stations 1, 2 or 5. I.e., Station 3 appears to be hydrographically isolated from the direct influence of Woodland Creek.

At 12:20 a series of surface floats was released in a transect perpendicular to the concrete boatramp near the airplane runway (near Station 34). This location is just over 100 yards south of the cove entrance. A light wind was coming from the south and southwest. Each of seven floats was released at an approximate 30-yard interval, starting 30 yards from shore, to observe which (if any) would enter the Station #5 cove. The float nearest to shore ran aground on the shoreline prior to the cove whereas the float released 60 yards from shore headed directly for Station #5. The float released 90 yards from shore passed by the mouth of the cove, and the other floats passed the cove further out (to the west). At 12:36 the float which passed close to Station #5 was drifting out of the cove.

Another series of float releases was conducted at 12:40. Six surface floats were released at 50-foot intervals, starting 50 feet from shoreline, in the same transect as the previous release. All of the floats released within 200 feet of the shoreline ran aground on the shoreline south of the cove. The float released 250 feet from shoreline entered the cove. The surface float released 300 feet from shoreline headed directly up the inlet and did not approach the cove.

A third float release was conducted at the immediate south of the cove at 1:17. The float released ten feet offshore entered the cove, whereas the float released 40 feet offshore avoided the cove, moving directly up the inlet. The results of these three series of float releases are similar, and help explain how fecal coliform levels in the water immediately south of the cove mouth can impact water quality at Station #5 on ebbing tides.

Fecal coliform samples and salinities were collected in or near the cove from 12:46 to 1:06. The results are as follows:

<i>SAMPLE LOCATION</i>	<i>FC/100 ML</i>	<i>SALINITY (ppt)</i>
South of cove mouth	23	20
Station #5	70	5
South (creek) branch	110	0
North (creek) branch	49	0
North of cove mouth	49	17

These results indicate, by the salinity readings, that the water at Station #5 was influenced during this sampling both by the creeks (contributing freshwater) and the (saline) inlet water. However, this degree of mixing or influence is not consistent at Station #5, even considering only ebb tide cycles. For example, during this investigation, the extent of a freshwater lens was visible on the water surface. Salinity varied from 4 ppt to 20 ppt on different sides of the boat a few yards west of Station #5. However, this delineation of mixing of inlet waters with creek waters in the cove has been observed at different locations, as will be described in the following paragraphs.

#### JANUARY 27

On January 27th DOH and TCEH collected water samples for fecal coliform analysis during a dry period, on a tide with a range of 11.4 feet. No more than 0.20" of rain had fallen during any day in the week previous to this sampling. A high tide of 14.7 feet was at 10:29 AM and a low tide of 3.3 feet was at 5:29 PM. Sampling occurred between 2:18 PM and 3:00 PM. Station 34 is located just over 100 yards south of the cove entrance near the private airstrip (see map). The results are listed below.

<i>SAMPLE LOCATION</i>	<i>FC/100 ML</i>	<i>SALINITY (ppt)</i>
400 yards south of Station #3	49	13
Station #34	9.3	13
100 yards east of Station #34	33	14
Station #5	13	9
Confluence of 2 creeks in cove	14	0
Station #6	13	9

Salinity readings (again) suggest that the water at Station #5 is partially mixed with freshwater from the creeks in the cove. In addition, DOH and TCEH observed a salinity divergence line (the boundary of the surface water lens) between Station #5 and the confluence of the creek mouths. However, a surface float released at Station #5 moved directly out of the cove during this later stage of ebb tide.

#### FEBRUARY 1

DOH and TCEH collected fecal coliform samples on February 1 following a very intensive rainfall event that dropped approximately two inches of rain in the previous 24 hours. A high tide of 12.4 feet was at 2:08 PM, and a low tide of 0.1 foot was at 9:46 PM. The results collected on this ebb tide (with a range of 12.3 feet) are listed below.

<i>SAMPLE LOCATION</i>	<i>FC/100 ML</i>	<i>SALINITY (ppt)</i>
400 yards south of Station #3	95	20
Station #34	540	10
100 yards east of Station #34	540	9
Station #5	540	4
South creek mouth	240	0
North creek mouth	350	0
Station #6	920	10

It is difficult to make conclusions from the data listed in the table, due to the extreme intensity of rainfall that fell immediately prior to this sampling. This area of Henderson Inlet is closed to shellfish harvesting when more than (only) 0.5" of rain falls in 24 hours. However, some mixing of inlet water with creek water is evident at Station #5, even though the entire cove appeared to be turbid. The salinity (4 ppt) at Station #5 was surprising since an even lower salinity was observed a few yards to the west of it. On closer inspection, DOH and TCEH observed a ribbon of clearer inlet water pushing through the turbidity on the south mouth of the cove directly to Station #5. The ribbon of inlet water helps explain the higher salinity observed at Station #5 on this day than at locations immediately to its east and west.

#### SUBSEQUENT HYDROGRAPHIC AND DATA EVALUATIONS

Following the field observations and studies, the TCHD sorted water quality data at Station #5 by several parameters to observe any correlations with degraded water quality. The parameters included rainfall, salinity, fecal coliform results, stage and phase of tide, wind speed and direction, and season. All water quality results collected from 1/23/96 through 10/4/99 were used in this assessment. The sorting evaluations include the following observations for Station #5:

1. Elevated water quality occurred 20 times during the four-year period. Eleven results were greater than 43 FC/100 ml, while nine had levels between 14 and 43 FC/100 ml.
2. Thirteen of the 24 samples collected during ebb tides occurred two hours or more after the start of ebb tide. During this period of ebb tide, six results were greater than 43 FC/100 ml and nine were greater than 14 FC/100 ml. None of the 12 samples collected during the first two hours of ebb tide were greater than 43 FC/100 ml.
3. No circulation patterns were studied in the field during flood tide cycles. Therefore it cannot be determined how long into the first part of the flood tide phase that the flow from the head of the inlet may continue to have an impact on water quality at Station #5.
4. A total of 58% of all samples were collected during tides of a moderate range, versus 42% during tides with a large range. However, 75% of the results greater than 14 FC/100 ml were collected on tides with a moderate range, while 25% occurred on tides with a large range. A total of 73% of the results greater than 43 FC/100 ml was collected on tides with a moderate range.
5. It was noted during the field studies that the Station #5 cove surface water does not leave the cove during large portions of ebb tides of moderate range. Flushing of surface waters in the cove appears limited, especially in the inner cove near the creek inlets. Several surface floats remained within the cove for four days in December. Water quality violations appear more likely to occur during moderate tidal swings when flushing of the cove is reduced.

6. Wind from a southerly (SE, S, or SW) direction is associated with water quality observed at Station #5. Nine of the 11 results greater than 43 FC/100 ml, and five of the nine results between 14 and 43 FC/100 ml occurred when the wind came from a southerly direction.
7. Winds from the south tend to have a greater speed and be accompanied by rain in comparison to winds from other directions. Only two of 18 sampling events collected during southerly winds had no associated rainfall.
8. Wind velocity ranged from 8.5 to 21 mph during collection of six of the 11 samples that had results greater than 43 FC/100 ml. Rain was associated with all these (11) events.
9. Elevated water quality at Station #5 is associated with rainfall. Twelve of the 20 samples with greater than 14 FC/100 ml were collected when the rainfall accumulation during the four days prior to sampling exceeded the criteria in the DOH management plan for Henderson Inlet. Nine of these 12 results were greater than 43 FC/100 ml. Only two results with greater than 43 FC/100 ml occurred when the four-day rainfall accumulation was less than the management plan criteria.
10. Three septic system failures were repaired in the fall of 1998 on the west shoreline approximately 400 yards south of Station #3. During the field study of 12/12/99, inlet water passing within a few feet of the shoreline of these properties reached the area of Station #5 in approximately 15 minutes. At the site of one of these failures a grab sample result of the water entering the inlet was 215,000 FC/100 ml on 12/30/97. Since these failures could account for elevated water quality at Station #5 before their repair, the trend of water quality at Station #5 after completion of these repairs should continue to be noted.

## CONCLUSIONS

Empirical water quality results show that ebb tide is the adverse tidal condition for water quality at Station #5. The results of the December 13<sup>th</sup> floats and drogue study demonstrate that the waters of Woodland Creek traveled on a typical ebb tide from its mouth to the immediate vicinity of the Station #5 cove in approximately two hours. Other sampling results obtained in or near the cove demonstrate that inlet water enters the cove during many portions of ebb tide directly toward or through Station #5. Meteorological information indicates that winds from the south are associated with elevated water quality results at this station. In addition, a high proportion of samples collected two hours or more after the start of ebb tide have degraded water quality.

Salinities of water samples from the cove show that the area around Station #5 appears to be a zone of mixing of water from the creeks and marine water brought in from the inlet. Fecal coliform results also indicate that the results at Station #5 could be a combination of creek water and inlet water. It therefore appears that the creeks that discharge into the Station #5 cove as well as Woodland Creek and/or other southern inlet sources contribute pollution to Station #5.

Measures to reduce pollution in these watersheds are recommended in order to improve the water quality at Station #5, which currently fails water quality standards. An example of such measures includes the repair of three residential onsite systems in 1998. These systems are located very close to the main pathway of Woodland Creek through the inlet on ebb tides, and hence could have been pollution sources for water collected at Station #5. However, water quality at Stations 1 and 2 demonstrate that pollution sources still exist in Woodland Creek and/or the more southern portions of Henderson Inlet.

The improved water quality at Station 3 (as compared to Station #5) appears to be due to its relative isolation from the direct path of the plume of Woodland Creek. The main pathway of Woodland Creek through this portion of south Henderson Inlet during ebb tide appears to flow to

the east of Station 3 but very close to Station #5. It is therefore recommended that the southern border of the Henderson Inlet conditionally approved area on the western shoreline be extended to the south, to include Station 3.