Dungeness Bay Bathymetry, Circulation and Fecal Coliform Studies: Phase 2

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1 INTRODUCTION

Fecal coliform concentrations measured by the Washington Department of Health (DOH) have increased in recent years in Dungeness Bay to levels that periodically exceed water quality criteria. As a result, DOH has closed a 210 hectare area of the Bay to shellfish harvest. This resulted in the closure of the commercial shellfish operations of the Jamestown S'Klallam Tribe. In accord with State of Washington law, a Shellfish Closure Response Team was convened to restore water quality. In accord with Federal law, the Washington Department of Ecology has conducting a Total Maximum Daily Load (TMDL) study of the Dungeness River (Sargeant, 2002) to establish allowable fecal coliform (herein FC) loading and facilitate restoration of water quality. This report involves the second phase of a study of Dungeness Bay and provides background information and results in partial compliance towards State and Federal requirements for a Bay TMDL. The phase 1 report is herein updated, amended and in a significant manner, corrected with year round and other more complete information.

Dungeness Bay is located on the Olympic Peninsula near the eastern end of the Strait of Juan de Fuca (Figure 1). The bay is partly enclosed within a remarkable and beautiful 8.4 km long sand spit that extends eastward into the Strait of Juan de Fuca (Figure 2). The Dungeness River is the main freshwater tributary to Dungeness Bay. The river's drainage area contains glaciated mountains and other areas of the Olympic Range, timberlands, agricultural lands, a wildlife refuge, and rural residential development. The river also is the source of water to ~270 km of irrigation ditches, from which the return flow discharges back to the river and to the Inner Bay.

Figure 1. Vicinity map of Dungeness Bay and Spit within the circled area. The Dungeness River is shown to enter just east of Dungeness Spit and the Elwha River is shown to enter west of Ediz Hook near Angeles Point. (After Thompson 1981)

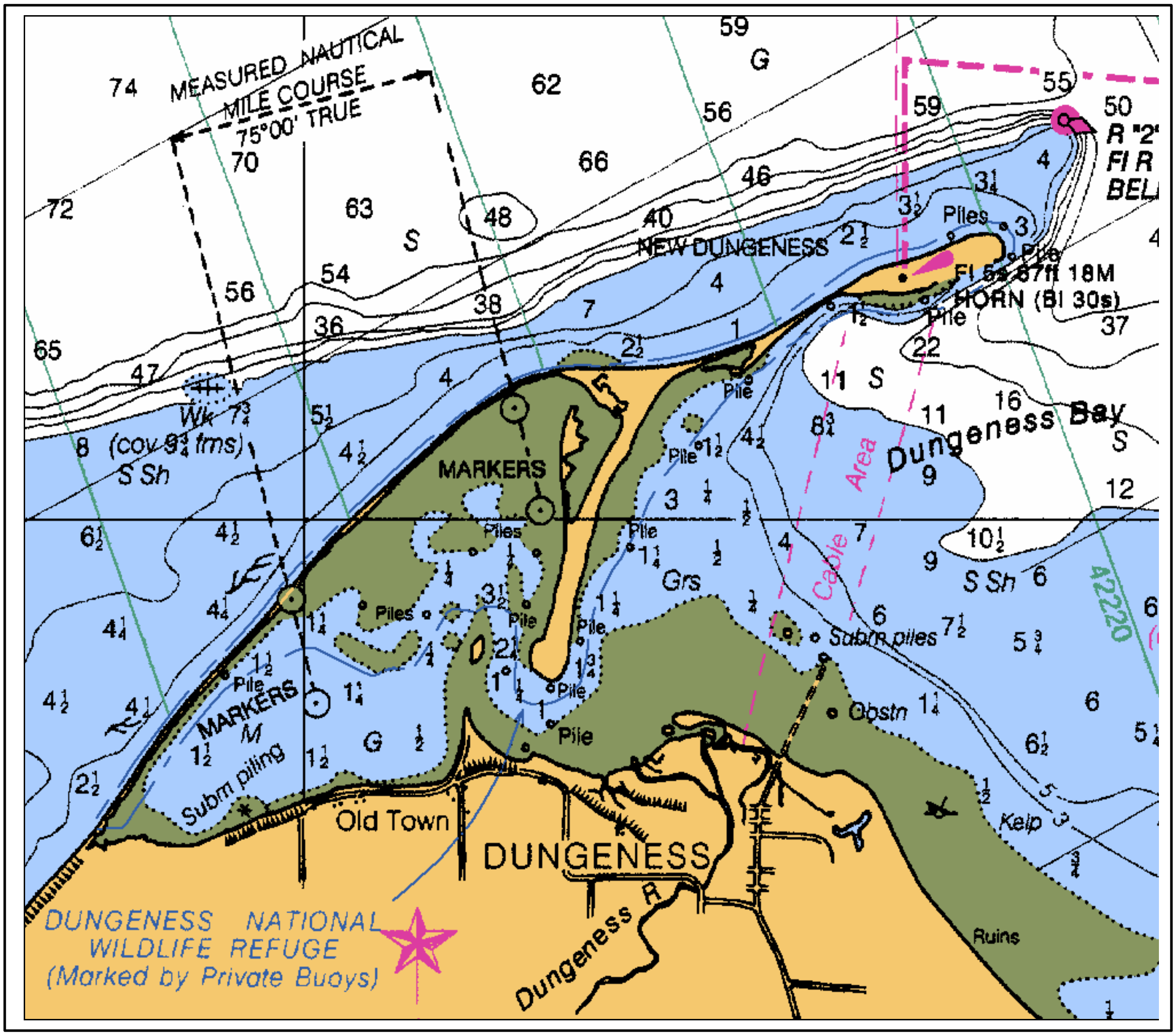

Figure 2. Portion of NOAA Chart 18465 showing generalized features of inner (left) and outer (right) Dungeness Bay. Depth in fathoms, but Inner Bay isopleths only generally correct. Landforms and depths are approximately correct except for river mouth area and in the northern ½ of Inner Dungeness Bay.

The Dungeness River watershed area's population is growing as shown by Clallam County's population growth from 56,210 to 64,525 (a 14.8 percent increase) between 1990 and 2000 (www.ofm.wa.gov/census2000/index.htm). Nearly all of the intra-census growth occurred within the Dungeness watershed. This growth has converted commercial agricultural and forested lands to medium-density and low-density residential development. The residential growth is increasing the number of small, non-commercial farms, septic systems (there is no wastewater treatment plant in the immediate vicinity) and suburban stormwater runoff, all of which are potential contributors of FC pollution.

Given these land uses the probable primary sources of FC appear to include (in no particular order): domesticated animals (including commercial and non-commercial operations); harbor seals, birds and other wildlife in and near the bay; wildlife in riparian corridors, failing onsite wastewater treatment and disposal systems along the River. These are carried by streams, irrigation ditches and stormwater runoff from various land uses. The nature of stormwater is changing primarily because agricultural lands are being converted to residential use. But, given the large size and mixed land uses within the tributary area, numerous other non-point sources likely exist.

An important use of Dungeness Bay is the Dungeness National Wildlife Refuge that was established by Executive Order in 1915 to include much of Dungeness Spit and northern portions of the bay. The Order directs that this area be set apart "as a refuge, preserve and breeding ground for native birds" and prohibits any disturbance of birds within the reserve. The area continues to provide important resources for breeding and migratory native birds and other wildlife (USFW 1997). The restoration of Dungeness Bay water quality then is obliged to proceed without any attempt to diminish the abundance of native wildlife within the Reserve. As seen later in this report, wildlife populations are significant contributors to FC pollution at specific locations and times but other sources are significant too.

1.1 Project Aims and Scope

This study has been carried out to further investigate FC sources and losses within the marine environment of Dungeness Bay. The phase 1 field work was based on limited, fair-weather sampling, and relied on DOH data to some extent. This data are suitable for shellfish safety enforcement, but is inadequate for a thorough understanding of the complicated dynamics of the bay. Large uncertainty remained after the phase 1 study because of this and also because nothing was known about subsurface fecal coliform distribution. Typically, sampling of FC for shellfish protection involves wrist-deep sampling only. In a shallow but well mixed or mixing water column that would not be problematic, but at various times and places within the bay the water column is vertically stratified with respect to salinity and temperature. A specialized subsurface sampling unit was constructed and deployed to sample the subsurface depths for the present study.

The year-long study of fecal coliform conditions began in the fall of 2001 with the goal of collecting monthly data throughout the entire year. As in the prior study, concurrent wildlife abundance, rainfall, river discharge, and tidal data were collected. A bathymetric map and volumetric analysis complied by a subcontractor from the phase 1 was found to be significantly faulty and was recompiled for this phase (at no expense to the funding agencies). At the same time, older US government soundings from 1967 were used to construct a comparison map and estimate water volumes. This was done to investigate the possibility that the bay has become shallower than in the past. In the field work, surface and subsurface FC companion samples were collected whenever possible, allowing for a more accurate measure of the water column's FC content. A water budget for the study year was computed and an input/output model prepared to rationalize observed FC loads. It varies significantly from the phase 1 model both in construction and results. The report includes analysis and discussion of bird and wildlife FC contributions, mainly for the Inner Bay but also for the area near the river mouth. Recommendations for dealing with observed conditions and sources are included in this final report.

2 BATHYMETRY OF INNER DUNGENESS BAY

In phase 1 of this project an engineering subcontractor provided a bathymetric map from measurements collected in May 2000 (Rensel and Smayda 2001). The map itself was not as important as the volume estimates needed for flushing rate calculation. The initial map was prepared by a subcontract and the volume calculations were found to be incorrect due to a simple but serious mathematics error. Accordingly I reconstructed the map from raw data with the assistance of a new subcontractor, Evans Hamilton, Inc., a leading oceanographic consulting firm. In addition to preparing a general map and volume estimates, the company used National Ocean Survey (NOAA-NOS) “boat sheet” soundings data from 1967 to prepare a companion map. The purpose of the companion map was to investigate possible changes in depth and volume over the 33 year interval.

2.1 Revised Methods

Soundings were collected in Dungeness Bay bathymetry on May 30 and 31, 2000. Water depths were measured the first day and the mean high water perimeter measured the second day. On May 30, measurements were taken from a 19-foot Chris Craft center console outboard motor boat equipped with a Garmin Model 235 combination GPS/chart mapping depth sounder, a Trimble GPS and a laser level with stadia rod. The boat was motored at a fairly constant speed of 8 km/hr over a 32 km course consisting of 27 transects. Time, depth, latitude and longitude were recorded every 30 seconds over a 5 hour period. Data was periodically downloaded into a laptop computer. The depth sounder was operated primarily at 200 kHz (sometimes 50 kHz in eelgrass areas) and the measurements were frequently confirmed by sounding the bottom with an 8 m long stadia rod that was long enough to touch bottom throughout most of the Bay. Areas with eelgrass sometimes caused the depth sounder to perform erratically and in these cases, boat speed was slowed so that each reading could be confirmed with the stadia rod.

During the survey, on approximate ½ hour intervals, the tidal elevation was monitored using a Topcon Model HB laser level and temporary benchmark that we set up on Cline Spit Island in Dungeness Bay. The on-board stadia rod with laser level receiver was used to measure the elevation of the sea surface with respect to the laser level. May 30th was a good day to perform the bathymetric work because all afternoon the tidal range was quite small, measured to vary by 21 cm over the 5-hour study period.

The second part of the fieldwork was performed during a minus tide that occurred early the next morning. The boat delivered the surveyor to various beaches for him to walk along the shore to record longitude and latitude with the Trimble GPS. These locations were recorded near the top of the beach at the log line (the point of estimated mean high water) and at the water’s edge. About 20 percent of the shoreline was walked in this way, with particular focus on portions of the shoreline that were most irregularly shaped, such as corners, spits and the island with it’s associated sand bars. During this time, the laser level was reestablished on the island and water surface elevation regularly determined. The resulting data consisted of longitude and latitude of mean high water and (following correction for water levels) of mean low water locations.

NOAA maintains four navigational markers in Dungeness Bay that were used as horizontal benchmarks for the survey. These markers are located at a measured nautical mile apart and at an angle of 75° 00'. Predicted tidal height was used as a vertical benchmark. The predicted tidal height at the high tide on May 30 was 1.90 m and the low tide on May 31 was –0.17 m. Based on these two data points, we calculated the elevation of our temporary benchmark on the island. As a check of the accuracy of this vertical benchmark, actual tidal data from Station 9444900, Port Townsend, WA (http://co-ops.nos.noaa.gov/cgi-bin/co-ops.qry.cgi) was compared to predicted elevations for May 30 and 31, and found to be within 0.1 m, indicating reasonable accuracy. Data quality assurance measures also included the use of redundant GPS units to record latitude and longitude, use of the stadia rod to calibrate and confirm depth sounder measurements.

Orthogonal aerial photographs of Dungeness Bay from the Washington Department of Transportation and Jamestown S'Klallam tribe were analyzed with AutoCad software with a Surfer add on utility. These photos had been taken during relatively low tides in June 1993 and April 1999, and aligned based on the four NOAA markers that were visible in the photos. The bathymetric contours of the rough map were then displayed over the photographs. The contours were then manually adjusted to conform to the photographic record. The photographs were useful because of the great number of sweeping curves that exist within the Bay and that had been plotted in a more angular pattern when based only on the bathymetric data.

When the phase 1 map was reviewed by oceanographers at Evans Hamilton Inc., the shoreline location of this map was found to be approximately correct but was shifted significantly in a horizontal plane in addition to the depth errors previously noted. Accordingly the following process was followed to prepare a correct map for the year 2000 data:

1. The original data was reviewed for obvious outliers and compared to field notes where manual soundings had been taken by Rensel Associates.
2. When all the raw data had been inspected and corrected, tidal elevation corrections to MLLW datum were preformed using new estimates of actual tidal elevations during the surveying.
3. These data for latitude, longitude and corrected depth were fed into an AutoCAD program further supplemented with a Quicksurf contour profiling program.
4. Using AutoCAD Map horizontal positions were converted from Latitude and Longitude WGS84 decimal degrees to Washington State Plane NAD 83 meters. At the same time soundings were converted from feet to meters.
5. A scanned copy of the original Phase 1 map was aligned in AutoCAD for a best fit to the shoreline on NOAA chart #18440 and the bathymetric data from the May 2000 survey.
6. The MHHW line was then hand digitized off the phase 1, original map and was set to an elevation of -2.3m.
7. Using Quicksurf the Phase 1 MHHW line and the May 2000 survey data were then gridded to a triangulated grid with a 50m by 50m cell size.
8. 1m contours were calculated using Quicksurf. After review of the resulting contours two highly suspect survey points were removed from the data set. The grid and contours were calculated again using the same parameters as before.
9. Gross volumes were calculated using Quicksurf for the portion of the surface below the following depths; 9, 8, 6, 4, 2, 0, -2, and -4m. Gross volumes were also calculated for MLLW, MLW, MW, MHW, MHHW, 0, 0.7, 1.4, 2.1, and 2.3m respectively. Volume calculations were only performed on inner Dungeness Bay, the portion of the bay West of a line drawn due South from the South end of Graveyard Spit.
10. Net volumes were calculated for various slabs or segments of the water column by subtracting deeper volumes from shallower ones, see attached spreadsheet.
11. Quicksurf was also used to calculate total surface area and average depth.

For the 1967 comparison map, the following procedures were utilized:

1. NOS soundings downloaded.
2. Soundings converted from Lon/Lat/ z value (- meters) to WA. State plane, north zone, meters, (x,y,z values, meters).
3. Sounding imported to our AutoCAD system using an add-on contouring/modeling program named Quicksurf (QS).
4. Soundings gridded to a 50m by 50m matrix with simultaneous creation of a triangulated irregular network (TIN).
5. Soundings with 1m contour interval for QA/QC, errant points deleted (as NOS data are not perfect).
6. Edited soundings then gridded and contoured again.
7. QS surface volume utility used to determine volumes at the specified intervals. QS calculates volume based on the TIN surface.
8. Tabulation into spreadsheets.

2.2 **Bathymetry Results**

Dungeness Bay is composed of two, sequentially linked embayments, an inner bay with a narrow Entry Zone and an outer bay that is more of a “bight” than a bay due to its very wide opening to the Strait of Juan de Fuca. The Inner Bay is a shallow, triangular-shaped estuary enclosed by narrow sand spits. The mainland to the south of the inner bay is characterized by tall bluffs oriented east-west along the shoreline. The main sand spit, Dungeness spit, extends northeast from the bluffs 8.1 km seaward into the Strait of Juan de Fuca to enclose Dungeness Bay. A second smaller sand spit, Graveyard Spit, extends 2.3 km southward from Dungeness Spit, creating a narrow channel between its southern terminus and the mainland. Graveyard Spit separates Dungeness Bay into two parts, the outer Bay and the Inner Bay. The extent of the outer Bay is not defined in this report, but it extends at least as far as a line from the end of the main sand spit due south to the mainland.

Cline Spit and its associated small island further help to separate Dungeness Bay into its two basins. The spits are composed of sand, are devoid of trees and have low relief, with elevations less than 5 m above sea level. Except for Cline Spit, there is a nearly continuous accumulation of drift logs, several logs deep just above the mean high water level and that at some locations are distributed entirely across the spits. The Inner portion of Dungeness Bay is the portion that we mapped, and has a surface area of 4.66 km^2 at mean water tidal elevation. The distribution of area and gross volume as a function of depth are shown in Table 1 and Figure 3. Table 2 shows a comparison of net volumes for the present study versus the 1967 data that were analyzed.

Table 1. Morphometric and tidal characteristics of Inner Dungeness Bay, Washington using May 2000 sounding and revised analyses.

Parameter: Year 2000 Survey	Units	Mean Higher High	Mean High Water	Mean Water	Mean Low Water	Mean Lower Low
Tidal Elevation	Meters	2.3	2.1	1.4	0.7	0
Maximum Length	kilometers	4.79		4.53		3.35
Gross Volume per interval	10^6meters^3	14.19	13.14	9.69	6.62	4.16
Cumulative Surface Area	Km^2	5.57	5.18	4.66	4.05	3.07
Intertidal Volume	10^6meters^3			------------- 6.52 ---------------		
Average Depth	Meters			---------------------- 2.54 ----------------------		

Mean Higher High Water = MHHW, Mean High Water = MHW, Mean Water = MW,
Mean Low Water = MLW, Mean Lower Low Water. Intertidal volume is MHW-MLW or 6.52 x 10^6 m^3

Table 2. Comparison of water volumes by depth in Inner Dungeness Bay, Washington. Revised December 2002 using May 2000 field data.

minus (-) refers to elevation below MLLW, 0.0 m datum.
plus (+) refers to elevation above MLLW, 0.0 m datum.

Depth Range (m)	1967 Net Volume per Interval (m^3)	2000 Net Volume per Interval (m^3)	Percent Change by Interval
>9 (-)	17	0	-100%
8-9 (-)	449	0	-100%
6-8 (-)	6,564	0	-100%
4-6 (-)	48,128	4,652	-90%
2-4 (-)	1,166,941	209,574	-82%
0-2 (-)	5,154,511	3,943,440	-23%
>9 to 0 m (MLLW)	**6,376,609**	**4,157,666**	**35% decrease**
2-0 (+)	NA	8,469,974	NA
4 -2 (+)	NA	11,036,204	NA
MLLW to MHHW (0.0 to +2.3 m)	**9,450,324***	**10,033,414**	**6% increase***
Total – 9 m to + 2.3 m (-9 m to MHHW)	**15,826,933**	**14,191,080**	**12% decrease***

*some uncertainty of this estimate due to lack of detail in U.S. NOS survey drawings.

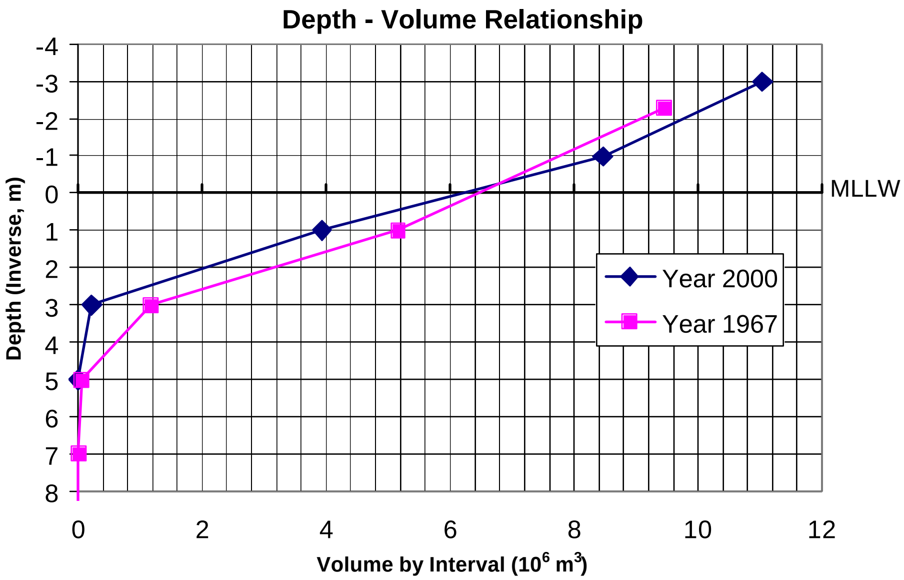

Figure 3. Depth versus Volume relationship for Inner Dungeness Bay, years 1967 and 2000. MLLW is the 0 m elevation ASL reference datum.

Negative depths refer to elevations above MLLW in this figure only.

Salient features of this analysis include:

1. Inner Bay volume below MLLW have decreased 35% in the 1967-2000 interval.
2. Intertidal volume may have increased about ~6%, but there is uncertainty about this estimate as the older U.S. NOS shoreline/MHHW mark was not well defined.
3. Cumulatively, there has been a significant loss of volume overall estimated to be ~12%.

Because of the magnitude of the estimated loss of deep water volume, the effect is probably real and could have a plethora of possible biological and societal effects. For boaters who have used the bay for decades, the bay should seem shallower at low tide and indeed some have reported that to be their view. Shallower volume of the inner bay would result in accelerated flushing rates, as intertidal volume remains the same but mean volume is diminished. But that effect on tidal current velocity could be masked by the breaching of Cline Spit that acted to reduce tidal transport speeds due to the addition of another inflow channel. Cline Spit was breached in 1978, (Swartz et al. 1987), which created the small island referred to in this report as Cline Spit Island. In part, the breaching of Cline Spit may have accelerated filling of the Inner Bay as it allows two entry and exit points, where previously there was only one, around the tip of Cline Spit and settling of solids could be enhanced in areas with reduced and opposing current vectors, such as the area just west of Cline Spit Island. A significantly larger entry area allows for reduced water velocity and scour than previously existed but once again, it is unknown how much this effect is offset by the accelerated flushing rates that result from shoaling. The effect of shoaling on fecal coliform conditions is not clear either, as accelerated flushing would reduce FC loading due to dilution, it could be offset by additional light and temperature bacterial die off effects. From comparison of 1967 and year 2000 maps (Figure 4), it can be seen that the western Inner Bay has similar -1 meter isobaths but there was a loss of large amount of the -2 meter depth zones (turquoise color line), particularly on the northern side of the Inner Bay. Nearer Cline Spit, there was a loss of much of the deep channel holes north of the spit, both to the east and west of the present day Cline Spit Island.

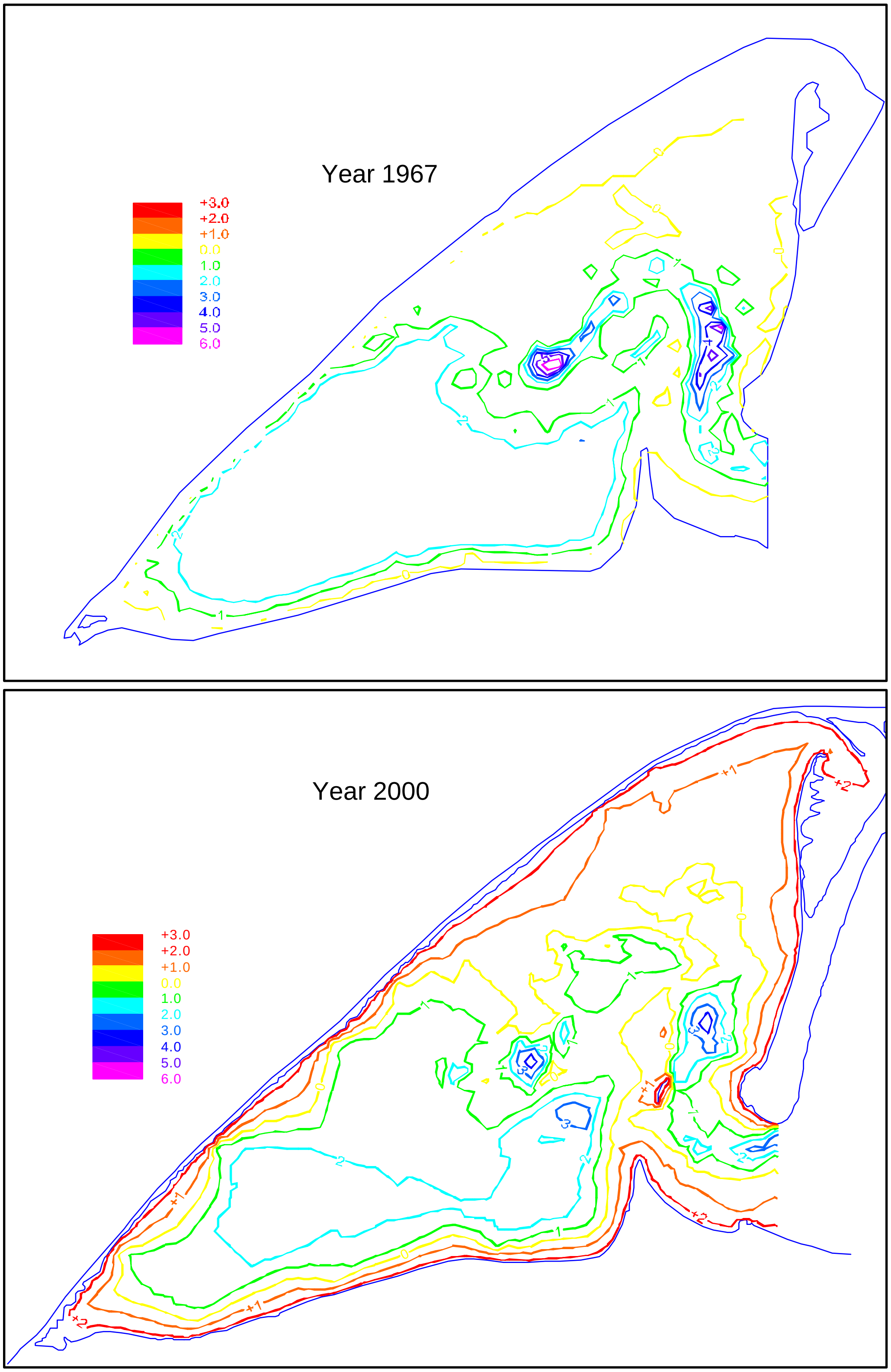

Figure 4. Bathymetric contour map of Inner Dungeness Bay from 1967 (above) and year 2000 (Below). Color key in meters depths below MLLW (0'). Plus sign indicates elevation above zero datum of MLLW.

3 REFLUX OF INNER BAY WATER

In order to further understand and model the fecal coliform dynamics of Dungeness Bay, a study of tidal excursion and return of ebbing Inner Bay water (i.e., reflux) was conducted. The study took advantage of the narrow constricted channel where all marine and some river water must enter and leave the bay together. Windowshade drogues (i.e., drift objects) were used on a specially selected day that had near average ebb and flood tide amplitudes of 1.4 m (4.4 ft). These days occur only a few days a year, typically in the late summer. Ideally, no unusually strong winds should occur during such a determination, and the effect of prevailing winds can be factored in later on a seasonal basis. This approach is predicated on the assumption that the bay has a steady state of tidal flushing over the longer term (lunar months) and that this steady state is approximated by measurements during near average ebb and subsequent average amplitude flood tides.

3.1 Reflux Determination Methods

The 23rd of September, 2002 had near average daylight ebb and flood tides and relatively mild conditions with an ebb tide of 4.0' and a subsequent flood tide of 4.5'. The mean tidal range for this area is 4.4' so the ebb tide amplitude was 9% less than the mean tide but the flood was nearly identical. At this time of year there were few crab pot floats and lines present that on other occasions could have snagged the drogues. An aluminum stadia rod was attached to a piling near the entry channel to the Inner Bay the prior day and its elevation surveyed into a nearby USGS benchmark on Cline Spit. In the early morning of September 23rd, at the beginning of ebb tide, strobe light equipped drogues were placed at the deepest part of the entry channel with the windowshade portion set to a maximum depth of 1.5 m. Water surface elevation was noted initially and recorded thereafter at least once every 45 minutes. Figure 5 indicates the predicted tidal amplitude that was very near the measured results. Red arrows indicate timing of drogue releases which were purposely more frequent earlier in the ebb tide. Drogue releases were timed evenly for the first ½ of the ebb tide, then spread out evenly over the remaining time.

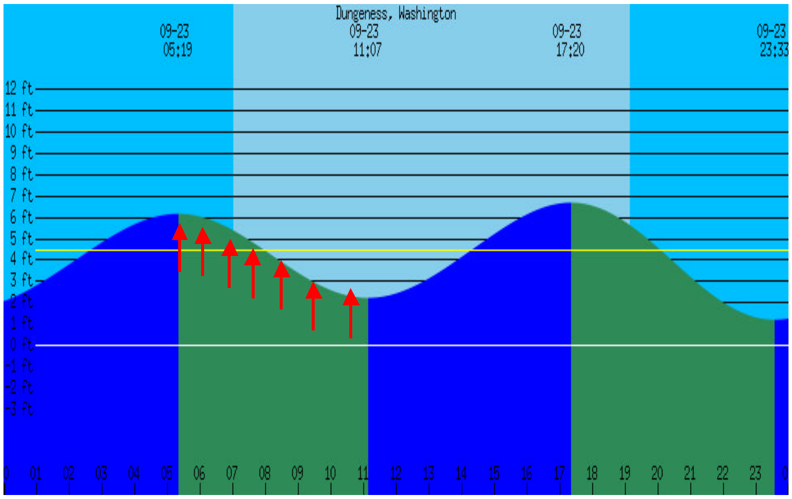

Figure 5. Tidal cycle plot from 23 September 2002 with red arrows indicate release times of drogues from the Entry Zone to the Inner Bay.

3.2 Reflux Survey Results

Figures 6, 7 and 8 indicate the beginning, and mid ebb tide drogue tracks. Early in the ebb all drogues moved briskly out of the entry area. As the tidal elevation was high, the drogues moved directly out the middle of the outer bay, not following the deep channel that follows the north side of the Outer Bay. In every case the early releases moved through the Outer Bay and rather abruptly entered into a southeast trending pattern that was previously described in the phase one report. The previous findings, which are further supported in the present study, indicate that drogues that pass an area approximately north-northeast of the old Three Crabs Beach pier continue traveling to the southeast, regardless of tidal phase. As pointed out previously, this means that septic tanks leaking directly onto the marine shoreline in this area would not affect Inner Dungeness Bay. The potential impacts of Meadowbrook Creek were not examined in this effort.

The pattern of drogues moving out of the Outer Bay and traveling southeast parallel to shore continued until the 6th release approximately midway into the ebb tide. Drogue number 6 made a round about turn and headed back toward and eventually past the release point. The subsequent released drogues followed the same pattern, with less excursion distance.

After accounting for differences from true mean tidal exchange, these results suggest that the average tidal exchange in Dungeness Bay results in a relatively high reflux or return rate of approximately 45%. This means that approximately 45% of the water leaving the Inner Bay returns back into the same area within a single tidal cycle (12.4 hour mean duration), and does so in less than 5.6 hours (0.45 x 12.4 hours). As explained later in this report, such a high reflux rate significantly slows the effective flushing of water from the Inner Bay and leads to conservation of water quality properties that differ significantly from those observed in the Strait of Juan de Fuca.

Additional reflux surveys were conducted during other average and extreme tidal conditions but are not reported here for brevity. In one case the survey was ¾ complete when a full gale blew into the area and resulted in extreme conditions unsuitable for completing the work. It is sufficient here to say that the patterns seen on the reported sampling day (September 23rd, 2002) were verified again in the other surveys, but since the drogue work was not completed on those other days, the ultimate return of drogues to the release point could not be verified.

From additional Outer Bay drogue releases in November 2001 and January 2002 I noted the existence of a flood tide, reverse-flow pattern near the south side of the main spit by the Dungeness Lighthouse. The phase 1 report cites other modeling studies that propose such a gyre, but no empirical evidence had been gathered. I noted areas of no water movement during mid tidal periods on another occasion about 400 m due south of the shoreline, followed by relatively fast clockwise motion on the flood tide. Such differences suggest the movement of the center of a gyre, which is common behavior seen elsewhere in nearshore marine waters. This gyre may not exist at the stated location at all tidal amplitude changes. For example, it was not present on the May 1, 2000 (moderate flood) drogue study reported in the phase 1 study. See Appendix A for a review of circulation in Inner and Outer Bay, extracted and updated from the Phase 1 study.

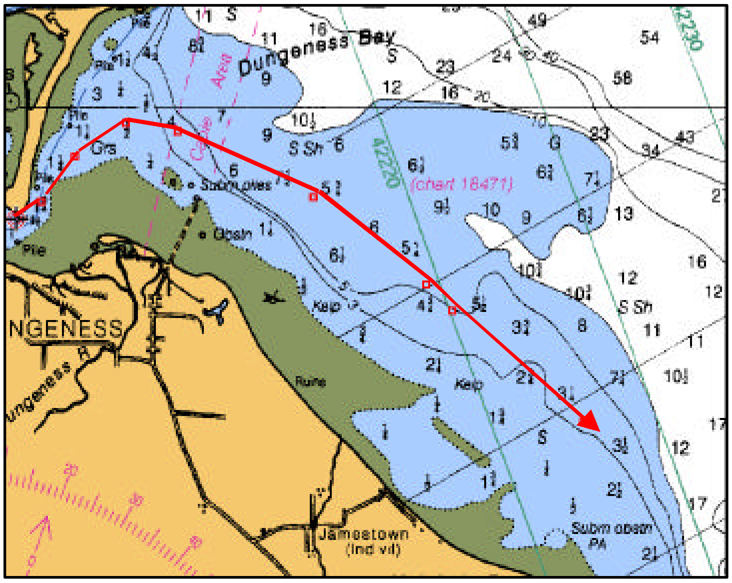

Figure 6 First release at 0535 hours, recovery at 1239 hours, still traveling SE, well into flood tide. Distance 7.5 km for mean velocity of 30 cm sec-1.

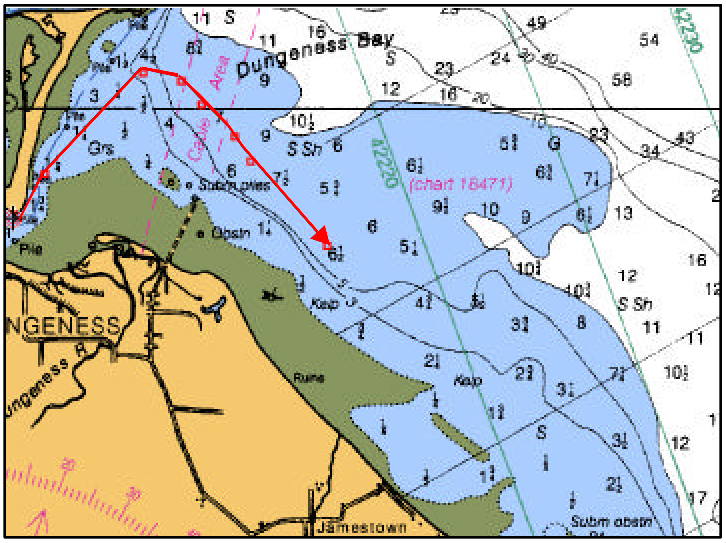

Figure 7. Release number 5 at 0735 hours, recovery at 1414 hours, traveling SE, more than ½ way into flood tide. Distance 7.5 km & mean velocity of 21 cm sec-1.

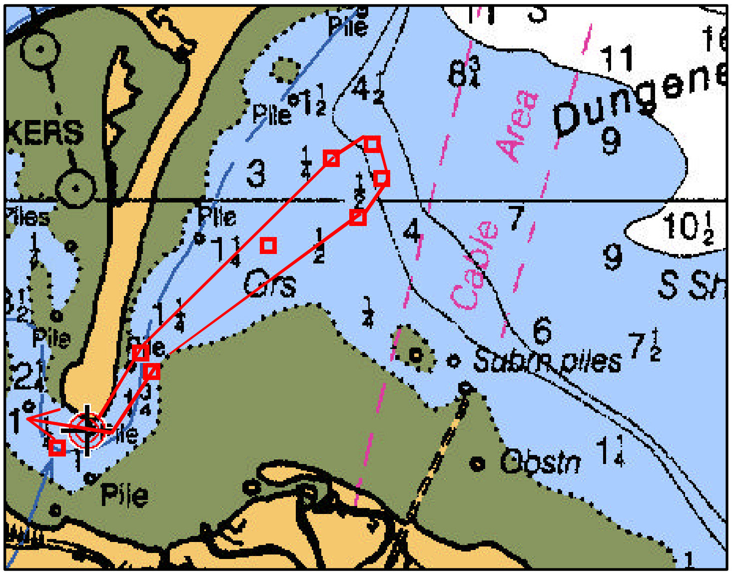

Figure 8. Release number 6 (D7) at 0835 hours, recovery at 1348 hours, traveling WNW into the Inner Bay, about 1/3 way into the flood tide. Distance 4.5 km & mean velocity of 23 cm sec-1.

4 TIDAL EXCHANGE ESTIMATES

Tidal exchange is the single most important factor in the water budget of Dungeness Bay, dwarfing all other factors including river flow. Tidal exchange varies as a function of tidal amplitude and location in the Inner Bay. A broad range of tidal exchanges and water re-entry fractions are expected to occur. Tides are semidiurnal in Dungeness Bay, with higher high, higher low, lower high and lower low tides generally occurring within a 24 hour 50 minute period. It is important to note that mean tidal range, which relates to flushing ability, in the subject area is not great at 4.4 feet (1.3 m) compared to central and southern Puget Sound where it ranges from about 8 to 10 feet (2.5 – 3 m).

The concept used here is that the outgoing ebb tide carries Inner Bay water into the main channel and sand flat areas of the Outer Bay and beyond, and the following flood tide will bring some of that same Inner Bay water back into the Inner Bay plus new marine water as the tide rises higher. This volume of this new marine water is variable based on tidal amplitude but over lunar tidal cycles becomes a constant. River water that is refluxed back into the Inner Bay may go through many cycles before escaping the Inner and Outer Bay combined, but for our purposes we are only concerned with the first tidal cycle as bacterial die off, sedimentation, predation and other losses reduce the FC load greatly in ensuing cycles.

Several basic methods are available for estimating rates of tidal exchange. It is important to note that all of these methods and intuitive common sense suggests that much of Inner Dungeness Bay flushes relatively rapidly given the overall shallow nature of the bay. In other words, the Inner Bay is relatively shallow compared to the average change in tidal height, i.e., the volume of water exchanged on the average tide is a significant fraction of the total volume. This starts with basic flushing rate estimation, essentially how much water leaves the bay on an ebb tide, followed by estimates of reflux which is defined as the Inner Bay water that returns from the Outer Bay on subsequent flood tides. Several increasingly accurate methods are used, following the example of Duxbury (1988). As previously discussed, flushing rate is slowed significantly by a relatively high reflux rate of water that returns on each flood tide from the Outer Bay and that factor must be accounted for in the following.

Tidal Exchange Method One: Volume Exchange

This method simply utilizes intertidal volume (defined in diurnal and semidiurnal tidal areas as the volume between the mean low water to mean high water marks) divided by tide cycle time to estimate the volume exchange rate. The resulting crude estimate is generally not highly accurate, but is useful to illustrate the basic concept that subsequent estimates are built upon.

For Inner Dungeness Bay, the average ebb tide has a 1.4 m drop from mean high to mean low water and discharges 6.5 million cubic meters of water $(13.14 - 6.62 \times 10^6 \text{ m}^3) = 6.52 \times 10^6 \text{ m}^3$. This volume represents about 67 percent of the mean volume $(6.5/9.7 \times 10^6 \text{ m}^3 = 0.67$, Table 2). Since $1/0.67 = 1.5$, if one incorrectly assumes that the ebbing water that has left the Inner Bay does not re-enter the Bay on subsequent flood tides, then the water is exchanged once every 1.5 tidal cycles. This non-conservative and over-simplistic water residence time is then 1.5 x 12.4 hours/cycle = 18.6 hours. I must emphasize that such basic approaches are not to be relied upon because inflowing water does not mix completely with Inner Bay water and due to reflux of Outer Bay water as mentioned above.

Tidal Exchange Method Two: Exponential Decay Model

A more conservative flushing rate estimate also assumes complete mixing within the Inner Bay but relies on a more conservative half-life calculation (Duxbury 1988). It has the advantage of accounting for the portion of flood water left behind in the Inner Bay on subsequent ebb tides. With each following ebb tide, a lesser amount of the original flood water remains, and the function approximates that of an exponential decay pattern where most of the water is removed in the first few ebb tides, but the flushing rate tapers off in a non-linear fashion that is described by a exponential curve asymptotic to the X (time) axis. The results of such a calculation are not a single point estimate, although often the time to 50% flushing also known as the “half life” is cited as an index of the speed at which water is renewed by outside seawater.

The basic formula is shown as equation 1:

Equation 1: % original water in Bay after T tidal cycles = $e^{-(\text{intertidal volume/average Bay volume})\text{x}(T)}$

For Inner Dungeness Bay, this relationship is described by the characteristic exponential shape of the curve in Figure 9. The half life of water in the Inner Bay can be deduced more simply from equation 1 by noting that the based of the natural log system e, raised to the -0.693 power equals 0.5 (Duxbury 1988). In other words, if we replace the entire exponential of *e* in equation 1 with the value -0.693, we may write a simple linear equation to estimate the half life of Inner Bay water as in Equation 2:

Equation 2 : 50% original water in Bay after T tidal cycles = $e^{-(-0.639)}$

The same expression may be rearranged for the number of tidal cycles T to achieve 50% flushing by using the properties of logarithms:

Equation 3: T = (0.639)/(intertidal volume)/avg. vol.)

Substituting values derived from Table 2 for intertidal volume and average volume (MW volume) we find that the water half-life is 0.95 tidal cycles. As there are 12.4 hours on average per tidal cycle, the estimated time for 50% flushing rate is therefore 11.8 hours.

Since about 50% of the water is replaced in 11.4 hours, 75% is replaced in 2 half-lifes or 22.8 hours, 87.5% in 34.2 hours, and so on.

The water budget must account for reflux of Inner Bay water returning on subsequent flood tides from the Outer Bay, which may be modeled as flows:

Equation 4: No. of tide cycles = (0.639)/[(intertidal volume/average vol.) x E]

where E = (100% - % reflux, i.e., recycled water/100).

Inserting the pertinent values yields:

No. of cycles = $(0.639)/[(6.53 \times 10^6\ m^3/ 9.69 \times 10^6\ m^3) \times (100\%-45\%/100)]$
$= 0.639/[(0.674 \times .55)]$
$= 1.7$ cycles x 12.4 hours/cycle
$=$ 21.4 hours for 50% flushing rate

This is shown in figure 9 for exponential decays with and without reflux considered. It takes twice as long to remove water completely when reflux is considered and given range of die-off rates of FC, this is a significant difference as shown in the next chapter.

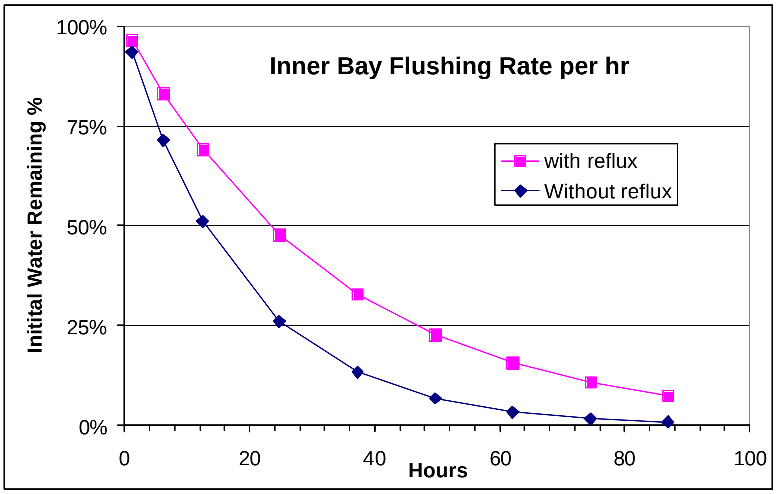

Figure 9. Estimated Inner Bay flushing rate with and without consideration of 45% reflux or return of Inner Bay water after leaving on an ebb tide.

Because tides have varying amplitude, the tidal water exchange and water resident time (inverse of flushing rate) in the Inner Bay also varies. With respect to FC bacteria this means that there are regularly occurring events of very slow water exchange, creating the possibility of exceeding water quality criteria because of the lack of dilution by clean marine water entering the system. However the duration of these extremes is short, less than a half a day. This short time period exists because a small tide is almost always followed by a large one, so that over two tidal cycles the range of water residence times is much less.

From prior circulation observations and discussion of tidal excursion, it is known that areas immediately inside the Entry Zone to the Inner Bay near Cline Spit and Cline Spit Island are very fast flushing, with water renewal from the Outer Bay occurring virtually every tidal cycle. Further west in the innermost bay, water is retained for much longer times, with more complete flushing only on larger ebb tides or series of ebb tides. So the flushing rate given above will be somewhat accurate for waters in the mid portions of the Inner Bay but will be faster to the east and slower to the west.

5 2001-2002 FECAL COLIFORM STUDY

5.1 Introduction

As stated previously, an important goal of sampling during 2001-2002 was to characterize fecal coliform conditions throughout Dungeness Bay with more precision than had previously been possible. This was to be achieved by the use of concurrent surface and subsurface sampling and more regular frequency of visits than has been attempted in the past. Phase one sampling in year 2000 had been restricted to spring to late summer, and so there was a need for a consistent, year round data collection. As explained in the Quality Assurance Project Plan (Rensel 2001), possible sources of physical and biological variation were monitored during the sampling year including bird and seal abundance, river discharge, rainfall, and vertical distribution of water temperature, salinity, and turbidity.

5.2 Overview of Sampling Strategy, Stations and Methods

Sampling strategy involved sampling of a variety of flood and ebb conditions, from average to extreme (Rensel 2000). Table 3 summarizes sampling dates, conditions encountered, tasks attempted as well as tidal phase and elevation during sampling.

Sampling frequency was initially intended to be monthly, but frequent problems with boats, storms and logistics resulted in multiple samplings for several of the months. No sampling was conducted in December 2001 due to engine problems. Repeated samplings in a single month were at least 2 weeks separate, so as to avoid the possible effects of autocorrelation. The frequency of such sampling was also spread out over the entire study year and selected seasons (as described below) so biasing effects on data analysis was minimized.

A Zobel subsurface sampler (Figure 10) was used to sample subsurface water at the same time surface waters were sampled at “wrist depth” (herein, 0.1 m). Subsurface in this study means ~2/3 of the total water depth to about 8 m total depth. Before the project commenced, I evaluated other alternatives but found none to be suitable. Some difficulties were encountered in use of the sampler, such as difficulties in assuring that the glass tube was broken and the bottle was filling when the sampler was deployed in turbid or deep water. The unit was designed to be applied to wire rope (cable), which was unsuitable for our use in a small boat. The unit was suspended by the use of Dacron line, which resulted in poor messenger operation at depths greater than 10 m.

Table 3. Summary of sampling dates, tasks, weather, wind, tidal phase and relative elevations.

Tasks: FC sampling = R, Circulation/Reflux = C, Sediment = S wind speed in kts.

					Tide Phase		Tide Elevation		
Date	Weather Conditions	Wind Speed	Wind Dir.	Task	Flood	Ebb	High	Med	Low
7-Sept-01	Cloudy	5	W	C,R	X	X	X	X	X
15-Oct-01	Light rain, no substantial recent rainfall	0	--	N	X		X	X	
8-Nov-01	Partly cloudy, no rain	0 - 5	W	R		X	X		
20-Nov-01	Very windy, heavy chop in outer bay	10-25+	SE	R		X	X		
7-Jan-02	Foggy, calm, relatively warm, heavy rain in PM, river floods	0	--	R		X	X	X	
4-Feb-02	Cloudy, dry, very cold, High wind/high waves PM	0 - 10	SE	R		X	X	X	
20-Feb-02	Dry, cold, sunny to partly cloudy	4 - 6	E	R		X	X	X	X
18-Mar-02	snow, pt. cloudy, rain showers	0 - 5	N to W	R	X			X	
15-Apr-02	Cloudy, cool, calm AM, full gale PM, dangerous	4 – 35+	S to W	C,R	X	X	X	X	X
30-Apr-02	Partly sunny, seasonal conditions	0 - 10		S		X		X	X
13-May-02	Very warm prior day, cool during sampling	0 - 12	W	R	X	X		X	X
23-May-02	cloudy, seasonably nice	5 - 7	W	R	X		X	X	
10-Jun-02	Cloudy AM, sunny PM	0 - 7	W	R	X			X	X
26-Jun-02	Partly Cloudy, no rain	5 - 7	W	R	X	X		X	X
15-Jul-02	clear, cool, patchy fog, dry, westerly	7 - 10	W	R		X		X	X
5-Aug-02	Calm AM, sunny but cool	0 - 5	W to E	R	X			X	X
27-Aug-02	Sunny, easterly swell in outer bay, warm in PM	0	--	R	X	X		X	
23-Sep-02	Sunny and calm	0	--	C	X	X	X	X	
24-Sep-02	Calm and sunny	0	--	R	X	X	X	X	

Figure 10. Photograph of Zobell sampler showing autoclaved glass bottle, stopper, and plastic tube, striker and messenger in technician's left hand.

5.3 Sampling Stations

Figure 11 indicates some of the place names used in this report. The river mouth configuration changed during high flow events of January 2002; the figure is not correct in that regard.

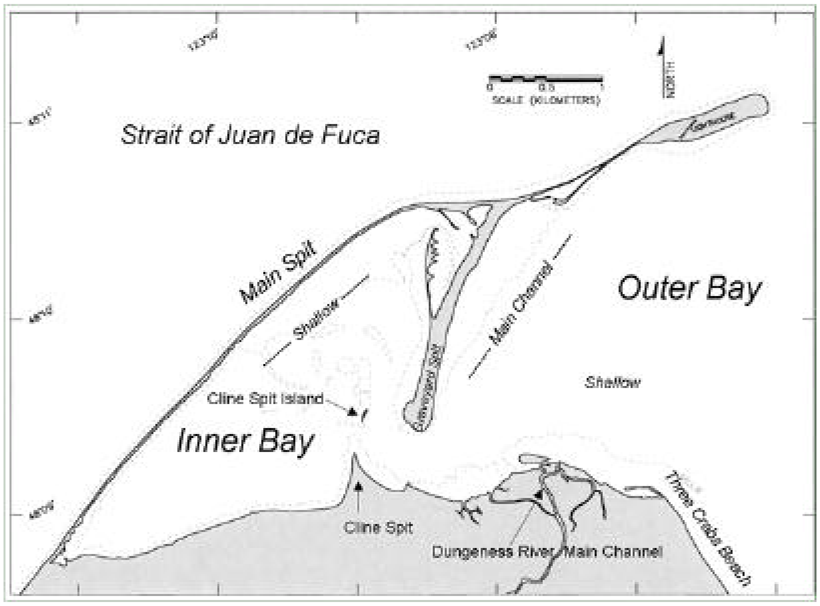

Figure 11. Vicinity map with place names used in this report.

Figure 12 shows the locations of subarea and fixed sampling stations also described below in Table 4. Some stations were primarily for characterizing FC and related conditions. Other stations were intended for the input-output mass balance model described later. Some sampling locations are not shown here as they were drogue tracking locations and other special circumstance samplings.

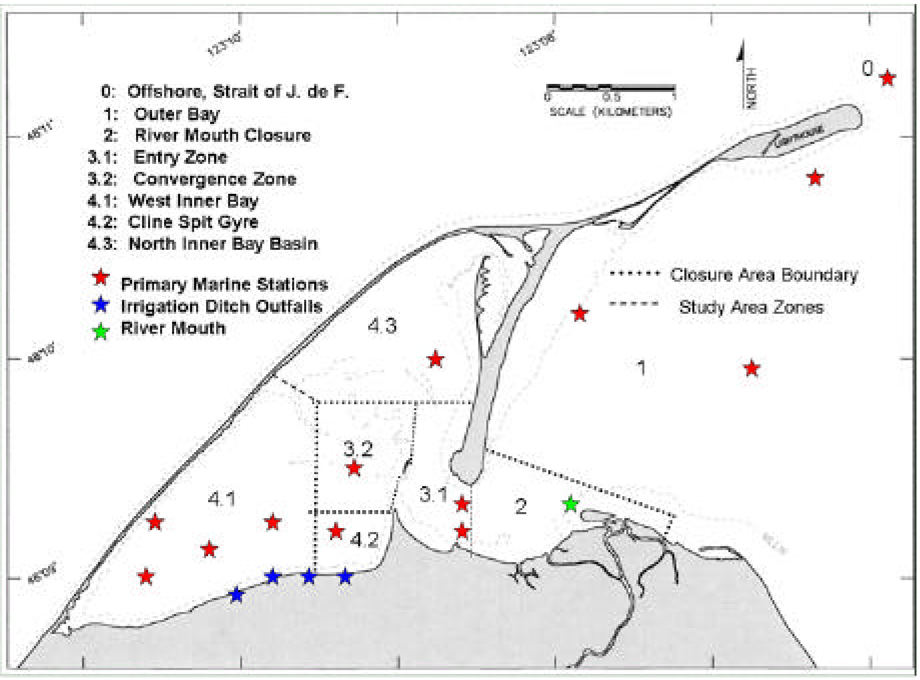

Figure 12. Study zone subareas and sampling station locations.

Some additional explanation of Table 4 and Figure 12 is provided here. Primary marine stations are those that were occupied on most sampling days unless weather or boat problems occurred. Special circumstance sampling locations not shown here may have been used to estimate conditions in a subarea, but only after inspection of sampling notes and water quality results (especially salinity) to insure that they were not associated with non typical conditions. Data excluded from the subarea groupings include all shallow and nearshore samples taken in shallow water immediately next to Cline Spit Island while sampling upstream and downstream of the seal haul out. These data could not be used to characterize subareas, as they were explicitly restricted to a discrete, small vertically-stratified portion of the water flowing through a subarea. Special purpose stations also included drogue sampling stations from the fall of 2001 and most of these data were later pooled into appropriate subareas. Drogue tracking was not continued later in the winter due to a lack of time and the prevalence of crab pots.

In most cases I sought to locate sampling stations to detect conditions for the bulk of the water moving through subject areas. This meant purposely sampling at locations that had more depth while neglecting shallow areas in some cases. This is the opposite of the approach taken by the Department of Health in their shellfish safety sampling, where stations are often very nearshore (e.g., DOH station 110 near irrigation outfalls nearest to Cline Spit boat launch). In addition, Figure 12 shows no stations north and east of the high water mark at the river mouth. Much of that entire area is very shallow and often not navigable at moderate to low tide. Moreover, drogue studies I have done demonstrate that waters east of the Three Crabs beach pier constantly flow to the south east, regardless of tidal stage. So sampling was not warranted despite the fact that the Department of Health has two sampling stations in this area. Similarly, the Inner Bay (area 4.3) did not have a station in its further northeast sector (DOH station 107) as this area was often too shallow to navigate on anything but a very high tide.

Table 4. Description of study zones and list of primary and other sampling stations.

Study Area Zones	Primary Stations	Other Stations	Purpose of Primary Station & Other Notes
O – Offshore	1	0	Reference area, Strait of Juan de Fuca
1 – Outer Bay	2	3	Near Lighthouse & center of bay routine stations. Others in main channel.
2 - River Mouth	1	1	River mouth station moved with tide, Channel station less frequently measured
3.1 Entry area	1	3	North channel station representing marine water and a south channel station to verify river plume. Also stations in Cline Spit Passage (west side of subarea) and upstream to downstream stations near seal haul out area on Cline Spit Island.
3.2 Convergence Area	1	1	To west of Cline Spit Island in poorly flushed area. Name is derived from flood tide entering around both side of CS Island
4.1 West Inner Bay	4	1	Multiple main stations in western area to cover a large area & possible variation
4.2 Cline Spit Gyre	1	1	Persistent counterclockwise gyre in small area near boat ramp
4.3 North Basin	1	1	Main station north and east of Cline Spit Island

5.4 Quality Assurance and Quality Control

Completion: There were nine stations regularly occupied for FC sampling over the 17 sampling days of the study year resulting in a possible total completeness of (9 x 17) 153 collections. Note this does not equate to 153 samples, but rather many more as several of the study zones had more than one sampling location. As shown in Table 5, 144 collections were made at these stations. Early on in the study, extreme weather prevented sample collection in the Strait of Juan de Fuca on one sampling day. Other stations were not occupied as we were trying to conduct drogue studies concurrent to routine sampling and found that there was insufficient time to do both. In the Spring of 2002, sampling was incomplete due to weather or boat motor problems, but additional sampling days were added later to account for this. For the most important stations used in the analysis, sampling was completed for 95 to 100% of the possible collections. Overall, many more stations within bay subareas were occupied and sampled than planned on in the original plan and scope of work.

Accuracy: The primary concern here was for station positioning and essentially the same results were found as stated in the phase 1 study. Additionally, a differential GPS unit was used for the reflux studies, which improved accuracy to within about 4 m based on real time measurements provided by the GPS unit. Then and at other times the unit was checked daily against a known piling location in the Inner Bay and found to be reliably close each time.

Replicate and Blank Samples: For assessment of precisions, duplicate samples, side-by-side surface water samples for FC were collected in the field routinely. Boiled, distilled water field blanks for surface and subsurface samples were also collected. Duplicate samples were not collected for subsurface samples using the Zobel sampler, as it took far too long to fill, be recovered, and be redeployed to sample the same water mass. In total, 799 samples were submitted for analysis of which 718 were marine, the balance were freshwater in the river or irrigation ditches. Additional samples for other experiments not reported in this report, i.e., bacterial die-off analysis, are not considered here. In order to verify that the precision of the duplicate analyses is within acceptable limits, the relative percent difference (RPD) of the duplicate samples are determined for each FC measured. The RPD is equal to the positive difference of the two measurements (cfu/100m/) multiplied by 100 and divided by the average of the two measured values. Acceptable limits were defined as < 40% in the Quality Assurance Project Plan (Rensel 2001) although this is probably overly conservative for an area like Dungeness Bay where mean values are often less than 10 to 20 cfu/100ml. Table 5 indicates that the goal was met as was the goal of 5% of the daily samples being field and laboratory blanks, separately.

Table 5. Summary of duplicate and blank sample results.

			Relative Percent Difference		
Source	**Type**	**Number**	**Minimum %**	**Maximum %**	**Average %**
Field Duplicate	Surface	38 (pairs)	0	131.4	24.1
Field Blanks	Surface	21	0	0	0
Field Blanks	Subsurface	21	0	0	0
Laboratory blanks	Combined	81	0	0	0

Representativeness and Bias: Dungeness Bay is an incredibly dynamic system, so the goal of having samples represent a full range of conditions was an approximation. Of the total marine samples collected (718), 350 samples were collected during ebb tide and 368 were from flood tides. Marine samples were collected during all types of tidal elevations, with some unavoidable bias existed among seasons, due to the nature of tides in the subject area and our limitation to conduct daylight sampling only for safety. For example, daylight hours of the late spring are dominated by low tide series but in the winter higher tides are dominant.

Changes of Sampling Plan: The initial sampling plan was expanded to include more subareas in the Inner Bay. Sampling equipment changed slightly too, as other types of multiprobes were used when the primary unit required maintenance. Laboratory samples for salinity and turbidity were relied upon during these events.

Companion Studies**:** Attempts were made to determine *in vitro* bacterial die off rates, but these studies were hampered by the unpredictable variability of FC content of the irrigation ditch water. As several treatments and controls were necessary, the sampling was complex and expensive and was predicated on having an initial FC content of at least 100 cfu/100ml. Attempts were made to spike bay and ditch water with FC from dog feces, which were successful and yielded reasonable results, but by the time that was completed it was clear that resources were too limited to continue the companion study.

Drogue studies were initially envisioned as part of the phase 2 study to see if there were seasonal differences in circulation compared to the Phase 1 (spring to fall) surveys. Intense use of much of Inner and Outer Dungeness Bay for crab pots prevented us from conducting extensive drogue studies, except for the reflux studies previously discussed. From the reflux studies and the other drogue studies some small changes in circulation patterns were noted, but overall the phase 1 circulation results were observed to be applicable to all seasons.

5.5 Seasonal Grouping

Seasonal periods were assigned for the study year in order to achieve sufficient data to calculate 90th percentile measures and to facilitate modeling of FC loading. River flow variation and change in pattern of daily FC concentrations were the primary considerations in this regard, but wildlife abundance patterns were also considered. For the purposes of this report the seasons are designated:

- Season 1: November through February inclusive,
- Season 2: March through July,
- Season 3: August through October.

These seasons are similar to those selected by the Department of Ecology (Sargeant 2002) for the Dungeness River TMDL study, but are continuous and include an additional period of late summer when river flows are low, and FC concentrations in most areas of the bay are relatively low. Many TMDL studies focus on wet versus dry seasons, but the year round presence and variation of wildlife indicated the need for complete annual coverage. The seasonal designations formed the basis for pooling of primary and some specialized sampling stations within subareas.

5.6 Daily Fecal Coliform Sampling Results

Geometric mean FC results for combined surface and subsurface depths are presented in Table 6. Only geometric means are considered here, as the time period and sample sizes are too restricted to allow presentations of 90th percentile distribution results. Data plots shown in this section are forced into 15 day intervals during the study year which results in slight shifts in actual temporal occurrence. Beginning with Strait of Juan de Fuca “offshore” reference station, Fig.13 shows low FC results near the reporting and detection limit of 1 cfu/100ml during the entire survey year. In comparison, Outer Bay stations showed a slight increase during early winter and spring, but geometric mean values remained relatively low.

Table 6. Geometric mean fecal coliform results from daily sampling.

Combined surface/subsurface samples, except River Mile 0.1 (surface only). River mouth shows surface values for up (A) and downstream of birds (B). Red indicates result exceeding or approximating the river TMDL bacterial target of 13 cfu/100ml or marine water quality criterion of 14 cfu/100ml.

	Off-shore	Outer Bay	River Mouth A	River Mouth B	River Mile 0.1	Entry Zone	Convergence Zone	West Inner Bay	Cline Spit Gyre	NE Inner Bay
15-Oct-01	1.0	1.0	1.0	--	11.9	1.0	1.2	1.0	1.0	1.0
8-Nov-01	1.0	1.8	17.6	--	15.0	1.7	5.0	3.0	--	--
20-Nov-01	--	5.4	14.0	--	17.3	21.1	22.8	21.4	--	13.9
7-Jan-02	1.4	5.0	20.0	--	20.0	17.1	11.2	17.0	32.0	4.0
4-Feb-02	1.4	2.1	4.0	--	20.0	4.0	8.5	14.9	11.3	2.4
20-Feb-02	1.0	2.0	12.0	--	10.0	2.2	1.4	6.1	2.8	2.8
18-Mar-02	1.0	1.0	1.0	8.5	1.0	1.0	2.8	3.7	1.0	--
15-Apr-02	1.0	2.0	5.5	--	100.0	1.4	--	1.2	--	--
30-Apr-02	1.0	2.6	35.5	347.9	--	1.2	2.2	2.6	1.0	1.0
13-May-02	1.0	1.8	28.8	23.7	11.0	8.1	6.0	2.2	2.8	1.0

	Off-shore	Outer Bay	River Mouth A	River Mouth B	River Mile 0.1	Entry Zone	Convergence Zone	West Inner Bay	Cline Spit Gyre	NE Inner Bay
23-May-02	1.4	3.4	8.0	31.3	24.6	2.4	9.0	1.6	1.4	2.5
10-Jun-02	1.0	1.1	5.6	28.5	4.8	1.1	3.0	1.2	1.0	1.0
26-Jun-02	1.4	1.5	9.0	25.0	21.5	1.9	3.5	3.8	10.4	1.4
15-Jul-02	1.0	1.6	9.4	7.5	7.3	1.5	3.5	2.5	4.3	2.8
5-Aug-02	1.0	1.0	29.6	27.7	42.7	5.1	1.4	1.4	3.2	--
27-Aug-02	1.0	1.6	14.8	18.6	15.7	1.4	1.0	1.0	2.5	1.4
24-Sep-02	1.0	1.0	10.8	34.3	21.9	1.2	1.0	1.0	1.3	1.4

Most areas had >2 samples per day, a surface and subsurface sample at one, but typically more than one station.

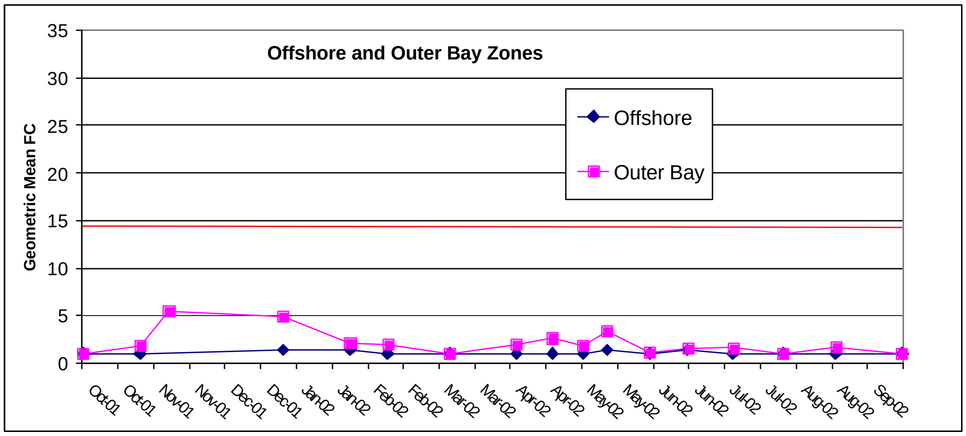

Figure 13. Offshore Strait of Juan de Fuca and Outer Dungeness Bay fecal coliform sampling results in daily geometric mean. Red line indicates state standard.

Moving westward to the inner bay, Figure 14 shows results for both the entry zone and the convergence zone which constitutes most of the shellfish harvesting closure area. Note that the results for these two subareas parallel each other fairly well, suggesting some continuity of FC sources and timing.

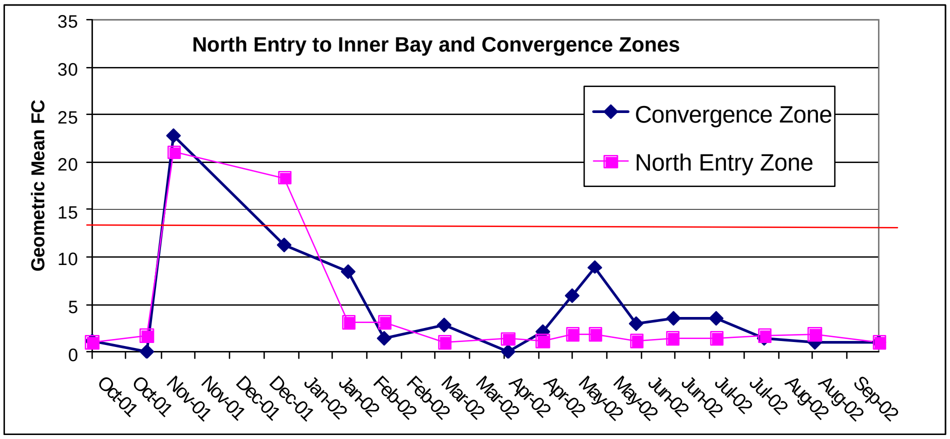

Figure 14. North Entry Zone to inner bay and convergence zone daily fecal coliform geometric means.

The temporal patterns shown in both Entry and Convergence Zones include low FC concentrations in the early fall, which previously was shown in the phase 1 report using DOH data to be the norm. Later in the fall, FC concentrations increased sharply to a peak in November that extended through January and exceeded the FC water quality criterion. The geometric means then declined during early spring and remained relatively low the balance of the study period. However, there was some notable variation among sampling days. Explanation for the temporal patterns shown here is discussed later in the FC modeling section of this report.

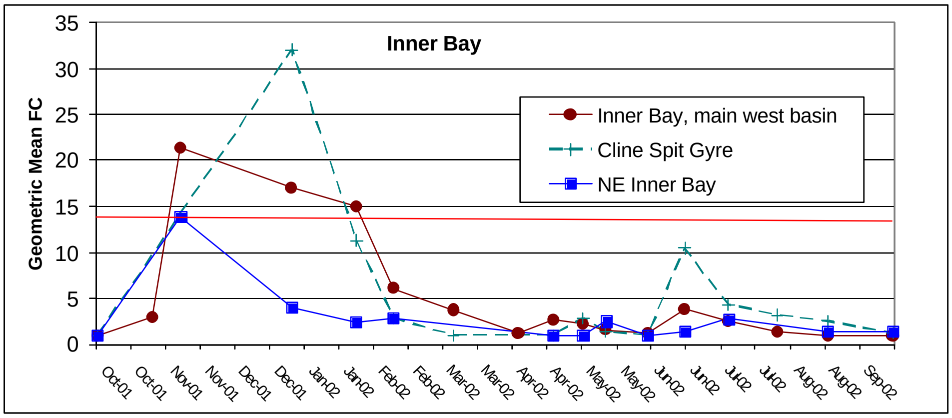

Figure 15. Fecal coliform sampling results in daily geometric mean for three inner bay subareas.

The same general pattern of high winter FC concentrations is seen at the remaining three Inner Bay sampling areas shown in Figure 15. Throughout the study year the most intensely sampled area was the West Basin of the Inner Bay. Note how the shape of the curve for the West Basin during winter closely parallels the Entry and Convergence Zone patterns in the prior figure. Subsequently in spring and summer the general trend for the West Basin was for lower FC results than in other Inner Bay areas.

Geometric mean FC for the river mile 0.1 station are shown in Fig. 16 as well as data from the Department of Ecology sampling further upriver and on different dates. Department of Ecology monthly water quality data was collected independently in the river during the time span of this study. The WDOE tabular results are not shown here for brevity, but despite the differing sampling dates, the magnitude and pattern of FC concentrations match fairly well.

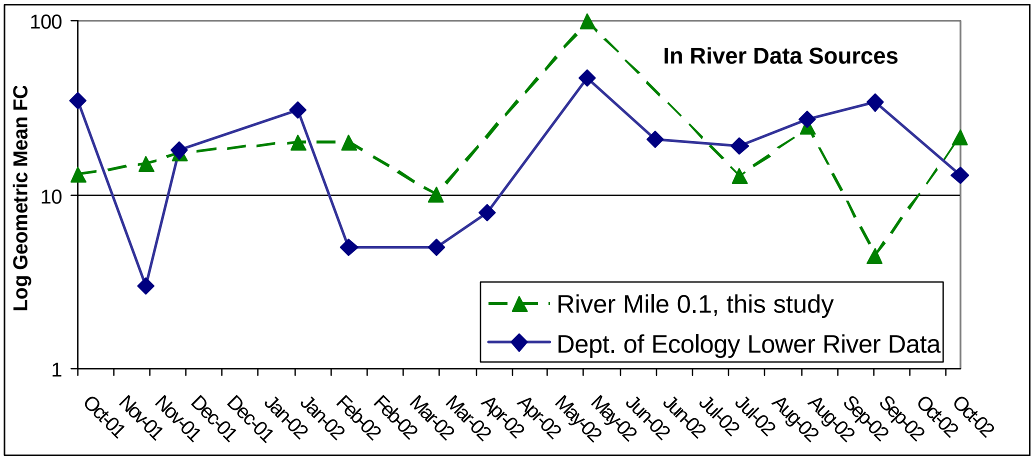

Figure 16. Dungeness River at river mile 0.1 versus Dept. of Ecology Lower River data from same time period, log geometric mean fecal coliform results.

The final station considered here is the Dungeness River mouth downstream of birds as shown in Figure 17 compared to Inner Bay stations. River mouth FC concentrations varied from low in October 2001 to much higher the following November through January, reverting to lower levels in February through mid April, and fluctuating again to higher levels in late spring and summer. The general patterns of geometric mean FC for the river mouth and Inner Bay stations shown in Figure 17 suggest a possible correlation during winter, which later in this report is shown to be possible but secondary to other sources and coincidental.

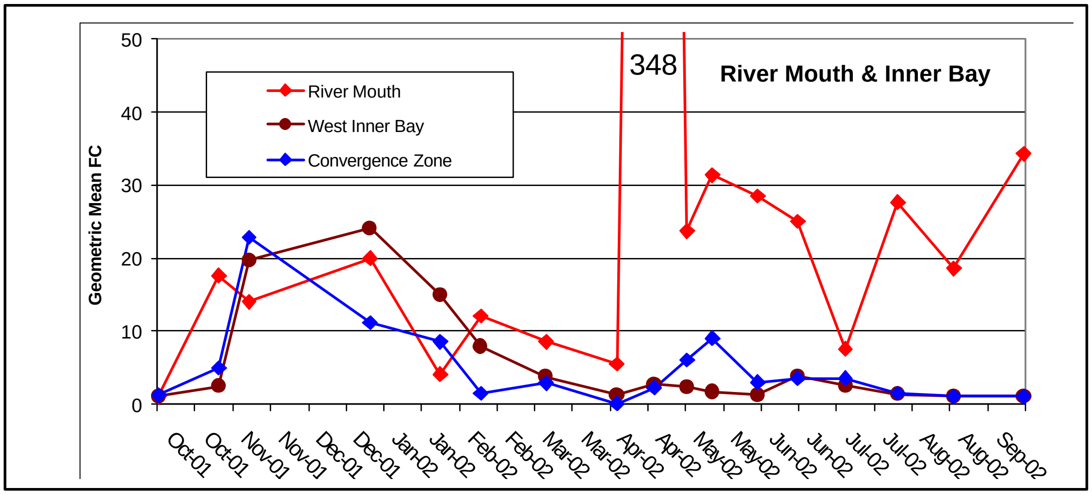

Figure 17. Dungeness River (surface water, downstream of birds) at river mouth versus West Inner Bay and Convergence Zone, geometric mean fecal coliform results.

The two sets of River Mouth data in Table 6 represent: (A) the winter or when upstream/downstream sampling around birds not done and (B) sampling downstream of birds, only possible in the spring and summer. The latter is generally representative of the river entering the bay as sampling locations were somewhat randomly selected downstream of the birds. For example, there were always several braided channels and no attempt was made to find the channel with the most likely impact.

Testing of statistical differences for River Mouth situations A and B was conducted using paired t-tests (Zar 1996) with results shown in Table 7. The data was divided into two slightly different time sets, October –February and March – September. Birds were present in the River Mouth vicinity in all seasons, but only during the mid spring and summer was the river channelized at low tide, allowing the discrete testing of upstream and downstream of the birds. Only log FC concentration was statistically tested. No differences in the results would be expected for river load, because discharge in the tested area was the same.

Table 7. Paired t-test results for river and river mouth stations [P(T<t) two tailed] with sample size in parenthesis.

	Annual	Oct-Feb	Mar-Sept
River mile 0.1 vs. river mouth (No birds or upstream of birds)	0.22 (15)	0.20 (6)	0.29 (9)
River mouth: up vs. downstream of birds	NA	NA	***0.01*** (9)
River mile 0.1 vs. downstream of birds	NA	NA	***0.001*** (9)

The seasons used were shifted by one month to compile and test the data as a result of bird occurrence. Two sampling days omitted: 1) due to a single missing station and 2) August 5th sample omitted as no gulls present in the river mouth.

The results show significant differences between FC concentrations up and downstream of birds in the time period that testing was possible, March through September. Significant differences also existed for the in-river station versus downstream of the birds. There was no statistical difference between the in-river station at river mile 0.1 and the river mouth station upstream of the birds or when no birds were present in the general area. Bird effects are discussed in more detail later in this report.

5.7 Seasonal Fecal Coliform Results

This section presents seasonal results by area and is of particular importance both in judging water quality compliance and for modeling use later in this report. As considerable data are involved in the seasonal assessment, I include the 90th percentile metric. Besides being a water quality standard for the subject waters, it is a useful measure of the degree of patchiness when compared to a geometric mean of a specific subarea. It is also of note that FC standards violation in Dungeness Bay sampling by DOH typically involves 90th percentile measures, not geometric means. One would expect more patchiness of FC occurrence when the sources are immediately nearby and have not been mixed, abraded and homogenized into the water column.

Table 8. Seasonal geometric mean and 90th percentile fecal coliform results by subarea.

	Off-shore	Outer Bay L	Outer Bay M	Outer Bay C	River* Mouth	River Mile 0.1	Entry Zone N	Entry Zone S	Conv erg. Zone	Cline Spit Gyre	W. Inner Bay	NE Inner Bay
Nov – Feb												
Geometric mean	1.2	1.5	3.3	1.8	10.5	16.0	5.5	3.1	6.6	10.5	8.9	3.8
SE	0.4	3.7	7.1	3.6	15.8	7.0	12.7	22.0	15.0	30.2	52.1	4.9
N	9	11	6	6	8	7	36	6	14	10	38	7
90th Percentile	2.0	8.0	15.0	7.0	29.6	24.0	29.0	30.0	25.4	42.4	45.4	12.0
Mar – Jul												
Geometric mean	1.1	1.7	2.2	1.1	14.5	12.3	1.5	2.5	4.2	2.2	2.1	1.7
SE	0.3	11.2	3.7	0.9	18.5	24.9	2.2	5.2	8.7	27.7	8.4	1.4
N	9	11	6	6	41	34	32	7	23	15	54	15
90th Percentile	1.3	3.5	8.6	8.6	40.0	53.4	5.6	9.6	17.6	11.6	12.9	4.0
Aug – Oct												
Geometric mean	1.0	1.0	1.4	1.0	19.2	21.2	1.3	2.2	1.1	2.1	1.1	1.4
SE	0.0	0.0	1.3	0.0	12.3	22.0	1.4	4.3	0.4	4.8	0.5	0.6
N	8	10	7	7	18	27	23	11	10	15	28	4
90th Percentile	1.0	1.0	1.0	1.0	42.0	53.6	3.0	8.0	2.0	9.4	2.0	2.0

* Includes division of outer bay subareas L = near lighthouse, M = main channel, C = center of outer bay. River mouth data includes all samples from surface only.

Geometric mean results (Table 8, Fig. 18) indicate:

- Low concentrations offshore in the Strait of Juan de Fuca and the Outer Bay

- Highest concentrations at Dungeness River, river mile 0.1, particularly during the Aug-Oct period, with winter months ranking next.
- Moderately less at the river mouth with a differing seasonal pattern
- Inner bay stations relatively low values except during winter

- Winter Inner Bay results sometimes exceeding the geometric mean FC criterion of 14 colonies per 100 ml
- Winter had highest results for all stations except the river mouth stations
- None of the marine stations had seasonal geometric means exceeding marine water quality criterion for the subject area.

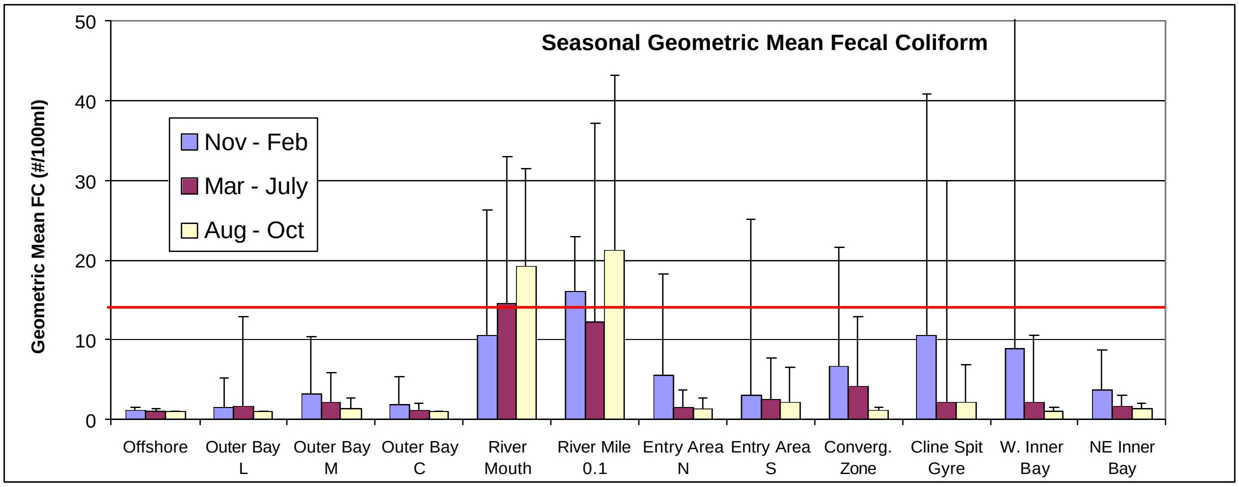

Figure 18. Seasonal geometric mean fecal coliform and standard error for sampling areas in and near Dungeness Bay during 2001-2002.

Figure 18 notes: Data includes subsurface data, which reduces results for several areas and increases it for others. Areas generally arrayed from east to west and the Strait of Juan de Fuca to the inner bay. Outer Bay codes are L = near lighthouse, M = main channel, C = center of outer bay. Data include surface and subsurface (except surface only for river and river mouth), flood and ebb tide results. Water quality standard indicated by horizontal red line.

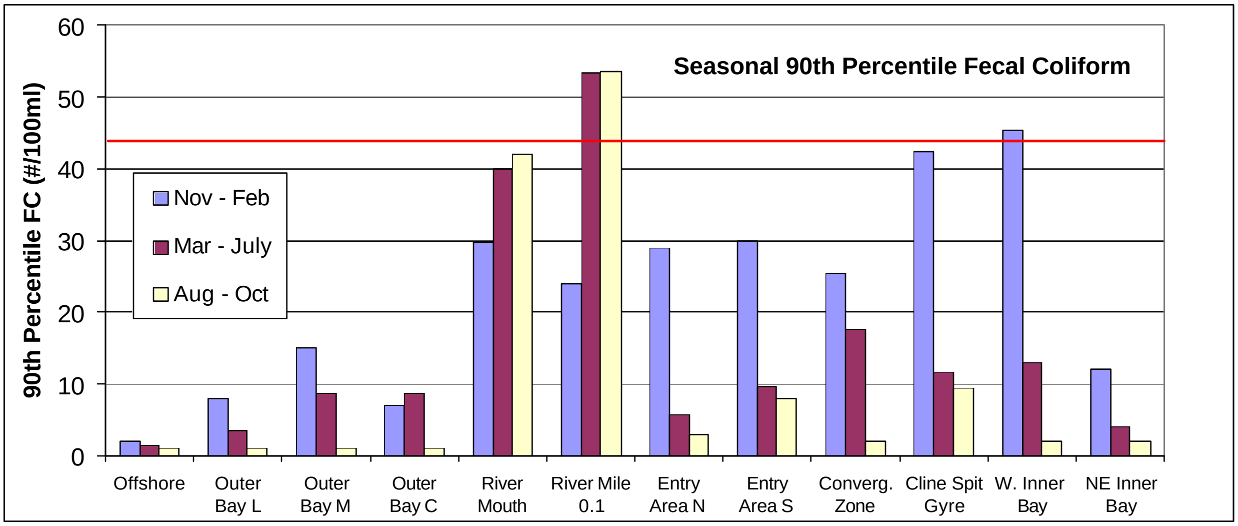

Figure 19. Seasonal 90th percentile fecal coliform for sampling areas in and near Dungeness Bay during 2001-2002. See notes for prior figure.

The 90th percentile fecal coliform measure (Fig. 19) indicates:

- Highest values were seen in the Nov – Feb season for 9 of 10 marine stations or areas.
- Highest results for river stations were in the other two seasons, exceeding marine water quality criterion of 43 colonies per 100ml in the river and coming close to it at the river mouth. This is a significant clue regarding other sources to marine areas discussed later in this report.
- River mile 0.1 and River Mouth results were comparable during spring and summer but both were markedly lower during the winter, in contrast to the marine station patterns. This also is a significant clue regarding other sources to marine areas discussed later in this report as discharge volume and loading is considered.
- Most Inner Bay areas had greater to much greater FC concentrations during winter than in other seasons.
- These data suggest that only the western and central areas of the Inner Bay were nearly, or in violation of the 90th percentile standard which is in contrast to long term DOH data. See the final section of this chapter for an explanation of the differences between the data sets.

Collectively, these data indicate the possible presence of significant sources of FC in the Inner Bay during winter season. Alternatively or concurrently, some factor may allow for accumulation and reduced bacterial die off in the Inner Bay. See the next section and *Recommendations* for a discussion of the unusual findings from the Inner Bay with regard to FC stratification.

5.8 Surface versus subsurface fecal coliform results

A conceptual model of bay circulation and vertical mixing was advanced as part of the phase 1 report. In brief, the Outer Bay was thought to be fairly well vertically mixed except where the river plume was present and depending on wind and tidal action. As water flows into the Inner Bay with the river plume, the relatively narrow and shallow channels south and north or east of Cline Spit Island were thought to partially mix river water into the water column. It was hypothesized that the Inner Bay might have relatively greater subsurface FC loads than the Outer Bay based on the conceptual model. Appendix B includes arithmetic mean concentrations of surface and subsurface FC results, along with temperature, salinity and turbidity and mean sampling depth values that were gathered together to construct Figures 20, 21 and 22 as well as Table 9.

In this analysis, “shallow” typically means 0.1 m depth and subsurface was about 2/3 of the water column depth for stations up to 8 m total depth. Most other stations of greater depth were typically sampled at 5 m depth for the subsurface as the sills at the entry to the Inner Bay were of about this depth. Results are reviewed here from east to west:

Offshore and Outer Bay Stations: Surface and subsurface FC values from the offshore reference station and Outer Bay stations were similar. Salinity, temperature and turbidity difference between depths offshore were minimal. Temperature differences between depths in the Outer Bay were minimal on average too, but some very modest vertical stratification of salinity and turbidity was noted in November through July period corresponding with increased river flow.

River mouth station: The data show increased FC content for surface water, inversely related to salinity content, for all three seasons with the differences increasing from winter to late summer. Vertical mixing in this area is in part of function of wind and wave action which would explain the seasonal differences between depths (but not the numerical FC results of either). Water temperatures averaged about a degree or two warmer in the underlying, saline water during the Nov to July period, but in late summer and fall the surface water was warmer by ~ 2℃. Turbidity was much greater in the surface, riverine water during the Nov - July time period only, and highest during the winter. Among seasons there was a major stepwise decline of mean surface or subsurface turbidity from > 80 NTU in the winter to 1 or 2 NTU in later summer and fall. Again, the CTD was equipped with a quality Wetlabs Inc. turbidity sensor and frequent calibrations indicating that it was operating correctly when used.

Entry Zone: Slightly greater FC values in surface waters were recorded during the Nov – Feb period, but at other times differences were minimal. These data are from pooled flood and ebb tides. Mean surface salinity during the Nov – Feb and Mar - July seasons were about 3 psu lower than for the subsurface depths. The difference dropped to only about 1.3 psu during Aug – Oct. Mean turbidity at the entry zone station during Nov – Feb was the greatest of any marine station in the surface waters during the Nov – Feb period (16.3 NTU), and lower at the subsurface depth (11.0 NTU). During late summer, however, mean turbidity had declined to the year's lowest values at the surface, but subsurface values were about twice as high. This could be related to plankton conditions discussed below in the section on the West Inner Bay.

Convergence Zone: Slightly higher subsurface FC concentrations were recorded in this zone during the Nov – Feb period, a phenomenon that was much more pronounced for adjacent waters of the West Inner Bay, discussed below. Although nominal, the trend continued into the Mar-Jul period and moreover, this area had the highest combined depth geometric mean FC value. Throughout the Nov-Feb season, the convergence zone had mean salinity results about 3 psu lower at the surface than the subsurface, similar to that of the entry zone (which had relatively low FC results) but about 1 psu lower than the adjacent waters of the West Inner Bay. This indicates the presence of river water[1], but the salinity values of ~ 27 psu in the very shallow surface layer (0.1 m) suggests that the river's load of FC was reduced by dilution by ~90% or just 1 cfu/100ml in that season.

Temperature differences were very minimal until the Aug – Oct period when pronounced differences averaging 2.6 ℃ were recorded. Turbidity in winter was higher in the surface waters but by late summer subsurface waters were markedly more turbid.

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[1] This assessment discounts the possible contribution of irrigation ditch return water to the convergence zone, as the volumes are very small and dilution would be massive if any of that water eventually flowed into the convergence zone.

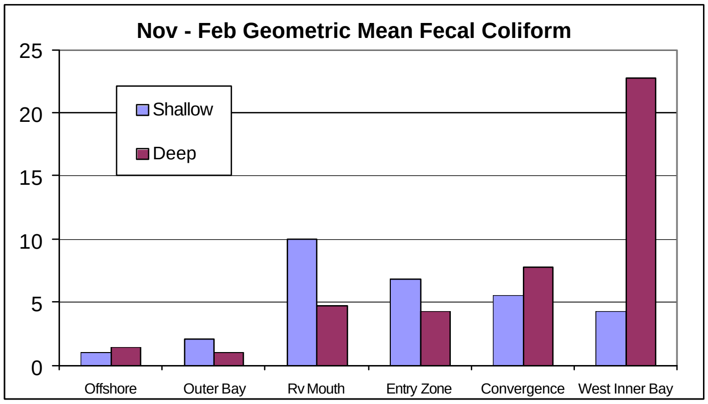

Figure 20. November through February geometric mean fecal coliform of surface versus subsurface samples.

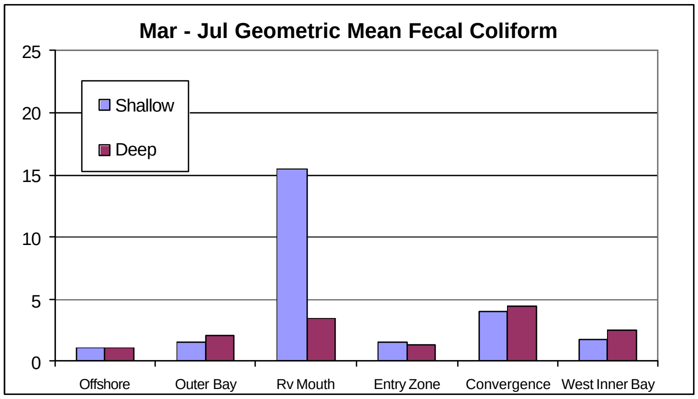

Figure 21. March through July geometric mean fecal coliform of surface versus subsurface samples.

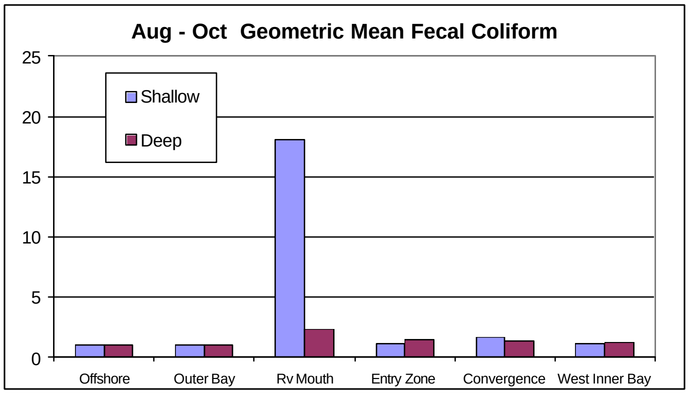

Figure 22. August through October geometric mean fecal coliform of surface versus subsurface samples.

Table 9. Seasonal fecal coliform, salinity, turbidity and water temperature of selected study areas, surface and subsurface depths.

Fecal Coliform cfu/100ml	**Nov- Feb**		**Mar - July**		**Aug - Oct**	
Geometric Mean	**Shallow**	**Deep**	**Shallow**	**Deep**	**Shallow**	**Deep**
Offshore	1.0	1.4	1.1	1.1	1.0	1.0
Outer Bay	2.1	1.0	1.6	2.1	1.0	1.0
River Mouth*	10.1	4.7	15.5	3.4	18.1	2.3
Entry Zone	6.9	4.3	1.6	1.4	1.1	1.5
Convergence	5.5	7.8	4.0	4.5	1.6	1.3
West Inner Bay	4.3	22.8	1.8	2.5	1.1	1.1

Salinity (psu)	**Nov- Feb**		**Mar - July**		**Aug – Oct**	
	Shallow	**Deep**	**Shallow**	**Deep**	**Shallow**	**Deep**
Offshore	30.91	31.38	30.86	30.98	31.72	31.88
Outer Bay	29.97	30.90	29.15	31.09	32.33	32.25
River Mouth	11.82	22.32	3.80	21.85	4.85	27.45
Entry Zone	27.46	30.32	27.46	30.32	30.01	31.55
Convergence	26.72	29.84	29.69	29.89	30.87	30.87
West Inner Bay	27.97	30.52	29.44	30.17	30.61	30.79

Turbidity (NTU)	**Nov- Feb**		**Mar - July**		**Aug - Oct**	
	Shallow	**Deep**	**Shallow**	**Deep**	**Shallow**	**Deep**
Offshore	4.8	2.0	1.1	1.3	0.2	0.2
Outer Bay	8.6	4.5	4.9	1.2	0.2	0.1
River Mouth	82.8	88.8	52.6	28.3	1.1	2.2
Entry Zone	26.9	8.1	6.6	5.8	1.1	1.2
Convergence	16.3	11.0	6.5	7.3	3.5	6.6
West Inner Bay	12.8	8.9	7.2	34.3	3.9	8.1

Water Temp. (°C)	**Nov- Feb**		**Mar - July**		**Aug - Oct**	
	Shallow	**Deep**	**Shallow**	**Deep**	**Shallow**	**Deep**
Offshore	7.9	8.0	9.3	9.2	10.4	10.0
Outer Bay	8.0	8.0	8.8	9.1	9.7	9.6
River Mouth	5.9	7.2	10.2	11.4	14.7	12.4
Entry Zone	7.8	7.9	11.4	11.1	12.2	11.4
Convergence	7.6	7.7	11.4	11.1	14.0	11.4
West Inner Bay	7.9	7.8	12.1	11.8	13.8	12.8

* River mouth FC data summaries include all data, FC loading analysis uses only an appropriate subset, as described later. These data can not be combined to yield overall geometric mean FC due to slight inequity in surface and subsurface sample size and because of the nature of geometric mean calculation, i.e., they are not arithmetic averages.

West Inner Bay: Elevated concentrations of subsurface FC (~23 per 100/ml) were noted in the Nov – Feb season compared to the surface depth (~4 per 100/ml). Because of intensive sampling in this area and quality control measures, the phenomenon was judged to be real, not a sampling artifact related to accidental disturbance of the bottom sediments or some other cause. During this winter season, the water column was vertically stratified with regard to lower salinity and greater turbidity at the surface, but inspection of the raw data showed no strong discontinuities, i.e., no sharp pycnocline. I examined the raw data to see if the difference in subsurface FC was related to some systematic error or just a few unusually high values that could be indicative of sediment contamination. But the data do not indicate such a possibility as there were no non-detections and many results well above normal background levels (subsurface winter Inner Bay arithmetic mean 34.1, SD 32.6 N = 15).

During the early January 2002 major flooding event, surface salinity in the West Inner Bay reached an annual minimum of about 22 psu and steadily increased to about 29 psu at 2 m. This compared to about 30 psu at the offshore station in the Strait of Juan de Fuca at that time. In early November, surface salinity in the West Inner Bay remained relatively high (~31 psu) but convergence zone (eastern Inner Bay) clearly showed the effects of the river with surface salinity near 24 psu. By late November, however, most areas of the Inner Bay had very low surface salinity (mean of ~ 23 psu), lower in fact than occurred in the major flooding events of January 2001. I attribute this difference solely to the presence of the easterly wind in late November. The 10 to 25 knot sustained easterly wind pushed the surface-oriented river plume into the Inner Bay and helped maintain it there even during ebb tides. Oceanographic references dealing with the Strait do not recognize the importance and persistence of these winds in the Dungeness Bay area in my opinion. This factor is one reason why use of river discharge alone as a possible index of Inner Bay FC conditions is not recommended.

Subsurface turbidity was twice as great as surface turbidity during this winter period, but the reason(s) are not known. It is possible that the elevated turbidity was due to resuspension of settled FC in association with fine silts and clays that could be due to extreme tides. Correlation of individual turbidity and FC results tends to negate that view with a correlation coefficient (r) of only 0.11. Moreover, sediment sampling in phase 1 and during the spring of this sampling year (discussed below) indicates that sediments may not be a major FC reservoir in Dungeness Bay.

Separately in the Mar – July period and more specifically during May to July, I measured a striking increase of subsurface turbidity in the West Inner Bay (Table 9, ~35 versus 7 NTU) but no concurrent increase in FC. The probe was recalibrated in the field but found to be accurate. On each of these sampling events I noted a huge subsurface peak of *in vivo* chlorophyll *a* from the Turner SCUFA sensor of my CTD, indicating the possible super-abundance of microalgae. Several sets of samples were collected and analyzed by a leading phytoplankton taxonomist showed this to be true, with an unknown small microflagellate in great abundance. The species are unknown and likely will remain so, but I am confident that the analyzed samples did not include the harmful microflagellate *Heterosigma akashiwo*, a prolific fish killer whose history in Puget Sound I have recently reported (Anderson et al. 2001). This phenomenon is not unique to Dungeness Bay as other studies I am conducting in the Strait of Juan de Fuca and Port Angeles Harbor and Neah Bay show similar trend at similar times (Rensel and Foster 2002). It is beyond the scope of this report to diverge into this finding, but it is of great food web and ecological importance to Dungeness Bay. Also not included in this report, but collected and analyzed, were dissolved inorganic nitrogen and phosphorus data that showed some periods of nutrient sensitivity in Inner Dungeness Bay. Several of these factors are indeed likely linked to one another.

5.9 Sediment Sampling

A preliminary study of sediment FC content was conducted during the phase 1 study. That involved stirring of shallow, nearshore sediments with the boat propeller in a systematic fashion at 8 locations in May 2000 and 6 locations in September 2000. Concurrent sampling was conducted for FC content (wrist deep) along with salinity and turbidity. The latter was used as a general index of the amount of sediments disturbed. From that study we found a possible decrease in surface FC content of 18% that was thought related to dilution of the surface water with deep water. In two areas, on the west side of Cline Spit Island at the seal haul out and near the Cline Spit boat ramp, we measured ~ 300% increase of FC. The former was undoubtedly related to seal fecal matter but the latter was unexplained.

To further investigate deeper, further offshore sediments as a possible reservoir of FC bacteria, in April 2002 I collected core samples from a petite ponar grab sampler from a number of stations in the inner and outer bay (Table 10). Sediment grab samples were collected and 2 cm deep x 2.5 cm diameter cores removed for FC analysis (MPN method). Sampling stations were selected along a semi-continuous transect reaching from Inner Dungeness Bay past Cline Spit Island and into the outer bay near the main spit.

Table 10. Summary of fecal coliform content of sediment sampling results in April 2002 in Inner and Outer Dungeness Bay. Detection limit (U) was 1 cfu/gram (dry wt).

Location	**Latitude**	**Longitude**	**Sediment type**	**~ Station Depth (m)***	**Fecal Coliform** cfu per gram
Far West Inner Bay	48.154298	123.161114	Silt and clay	3.5	1U
Center of West Inner Bay	48.152993	123.167950	Silty sand	4.2	2
East side of Inner Bay (west of Cline Spit	48.150294	123.173160	Silty sand	4.5	1U
West of Cline Spit Island near seal haul out	48.158469	123.153721	Silty sand	2.6	1U
River mouth at lower tide	48.158799	123.138477	Sand	0.3	1U
East side of Graveyard Spit	48.161077	123.139510	Silty sand	1.5	1U
Outer Bay main channel further east	48.166979	123.134219	Medium sand	1.2	1U
Outer Bay main channel furthest east	48.169863	123.130240	Fine sand	1.5	1U

* station depth relative to depth below MLLW (0 m) datum

The samples yielded non-detect levels of FC, except for one station in the western inner bay area that had just above detection level results at 2 cfu/gram, dry wt., Table 10). One of the sampling stations was just east of the west shore of Cline Spit Island near the seal haul out, but nevertheless resulted in no detection. Sediment grain size ranged from very fine (high % silt/clay) in the inner bay to coarse sand and small gravel in the outer bay. The data collected in the present survey indicates that deeper, further offshore sediments were not a significant reservoir of FC, at least during the time of sampling in 2002. Unfortunately, this work was not conducted during the winter season when relatively high subsurface FC results were encountered in the Inner Bay. At that time it is possible that sediments were a reservoir of FC bacteria. See *Recommendations* for a discussion of possible follow up actions.

5.10 Fecal Coliform Study Summary & Comparison to DOH Data

The design and implementation of this study did not include a goal of "checking" the validity of the DOH sampling results. Station selection was purposefully different, in that I selected stations that best represented geographic and loading averages which tended to be midchannel areas in some cases. Unlike the present study, DOH sampling is typically conducted at high tide or at least near the end of a flood tide, and was targeted on sampling conditions near beaches where shellfish stocks may occur. By collecting samples at high tide, the effect of the river is exaggerated somewhat, i.e., river water only enters the Inner Bay during high tide and die off is less of a factor at that time than later in the ebb tide. I do not take issue with this, as DOH is mandated to be conservative in their approach to protect the public.

It is therefore not unexpected that the results of this present study, which are arguably the most complete to date for Dungeness Bay, do not show major problems except in the winter for marine stations and year round near the Dungeness River mouth and adjacent marine areas. The inclusion of subsurface data in the present study for the Inner Bay in winter made for much higher FC results than would have been expected from the surface water samples collected by DOH. This finding is not only of practical significance but is of some novel scientific interest too (see *Recommendations*).

It is important to note that the phase 1 report reviewed existing DOH data and found some similar patterns in the historical data from the late 1980s through year 2000. Different seasonal designations were used in that study that in retrospect were not ideal, i.e., fall was defined as October through December inclusive. Taking this into account, the late fall and winter were the primary problem periods in the DOH database too. Springtime 90th percentiles in closure areas were relatively high in the DOH database (~33 cfu/100ml) both within and outside the current shellfish closure areas. In contrast, I did not find that to be the case in the spring of 2002 with 90th percentiles less than ½ of the long term DOH results. As depth of sampling was not a factor at that time, it is possible that this is an artifact of data set extent, i.e., DOH uses a much longer, multiyear period to calculate FC results.

The Dungeness River station (river mile 0.1) and the river mouth stations periodically failed to meet the marine geometric mean criterion of14 cfu/100ml. The in river station is normally not subjected to this criterion, but the Dungeness River TMDL has proposed a 13 cfu/100ml fecal coliform bacterial target for the river to protect bay waters. The Inner Bay definitely has a fecal coliform "problem" during winter months, particularly if the subsurface waters are mixed to the surface by wind or tide events.

There are other differences between the DOH program and the methods used in this study. DOH uses the most probable number (MPN, fermentation tube) analyses while the study relied on the membrane filtration method. EPA recommends the latter for marine studies and so did Washington Department of Ecology advisers to this project. One EPA reference (2001) reports that the MPN method has a 23% positive bias, but does not state the source of that conclusion. For an area such as Inner Dungeness Bay, such a bias could easily mean the difference between shellfish harvesting closures or remaining open. By law DOH must use the MPN method, but for TMDL work, the all round best method should be used. Samples were collected and analyzed by both methods in July 2002 for this study, but the six samples results were all detection limit or very low.

6 WATER BUDGET FOR INNER DUNGENESS BAY

Water and fecal coliform budgets are developed for both annual and three-season time steps to help evaluate the overall importance of the various components of these budgets. These budgets supercede annual estimates provided in phase 1 of this study, and are based on the time period September 2001 to October 2002. The water budget focuses on the Inner Bay only, which is bounded at the bay Entry Zone by a line drawn true south from the south end of Graveyard Spit.

6.1 Tidal and Marine Inflows

First I deal with "tidal inflow" by defining it as water entering the Inner Bay through the Entry Channel during flood tides. It includes water from the Strait of Juan de Fuca, refluxed water and Dungeness River water, carried by the rising tide. Tidal inflow is simply the basis from which other subset components can be estimated. It is practically equivalent to tidal outflow, as will be seen later, as evaporation in the Inner Bay and irrigation ditch contributions are insignificant compared to tidal inflow. Tidal inflow is simply the product of a time factor (hours per year) times intertidal volume of the Inner Bay divided by the tidal cycle period in hours as follows:

Equation 5. $\textbf{Tidal inflow} = (8760\ \text{hr/yr})(6.53\times10^{6}\ \text{m}^{3})/(12.417\ \text{hr}) = 4.61\times10^{9}\ \text{m}^{3}/\text{yr}$

6.2 Dungeness River Inflow

The Dungeness River obviously flows into Outer Dungeness Bay then into Inner Dungeness Bay during the rising tide. Only a small lag exists between the onset of the rising tide and the entry of river water. As soon as the ebb tide starts to flow, the river water stops entering the Inner Bay. Thus, river water enters the Bay approximately half of the time. There is a slack tide period in this area and water from the river pools up near the river mouth and is subject to non-tidal effects such as wind forcing. At high river discharges, this may cause a slug of river water entering the Inner Bay during the initial phases of the flood tide. At high tide the water again may pool up, but the ensuing ebb tide moves this water to the east, some of it escaping in the non-reversible flow to the southeast near Three Crabs Beach described in the Phase 1 report.

Dungeness River flow rate is influenced significantly by snowmelt in the Olympic Mountains, as revealed by the typical summertime peak flows (Fig. 23). Historical average flow ranges from a low of 174 CFS in September to a high of 705 CFS in June. The historical annual average flow rate is ~385 CFS. It is important to note that these data are from River Mile 11.8 at an elevation of 569 feet ASL.

During the study year, I relied on the Department of Ecology river gauging station near the river mouth, at river mile 0.75 (Fig. 24) as a more appropriate measure of the volume of freshwater entering the bay. The "up-river" station is above irrigation withdrawals. The reader should only compare the general shape of the curves presented in the below two figures, not the absolute values

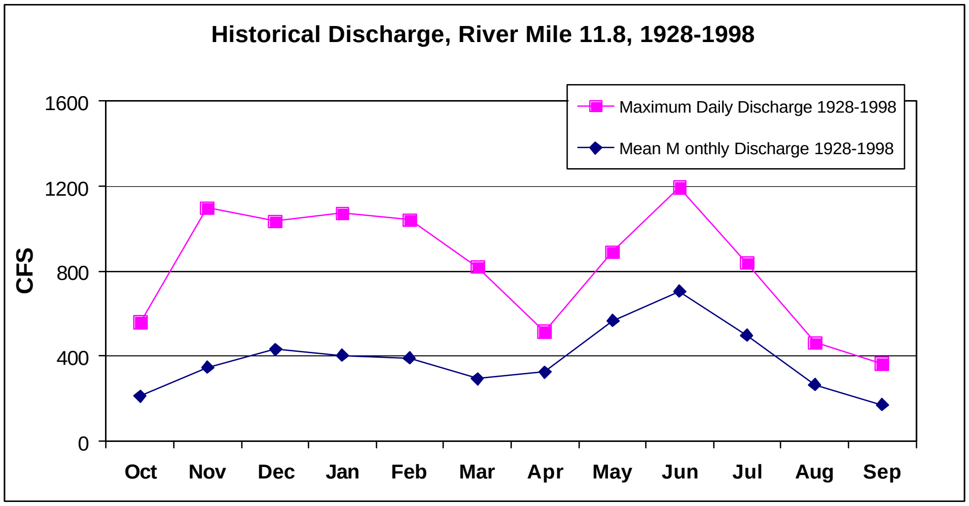

Figure 23. Average monthly and maximum daily discharge for Dungeness River, 1928 - 1998 at USGS Station Number 12048000, near Sequim, Washington.

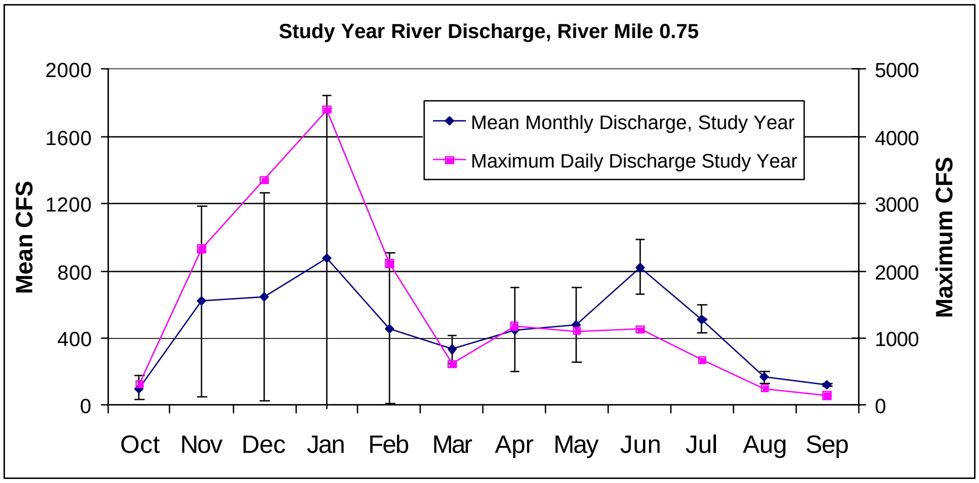

Figure 24. Average monthly (with SD bars) and maximum daily Dungeness River discharge from October 2001 to September 2002 at Department of Ecology River Mile 0.75 monitoring station (Station 18A050, near mouth).

The winter of 2001-2002 brought unusually high mean and maximum discharge rates for the river. The flood of early January 2002 resulted in a mean monthly flow of that month that exceeds the normally much greater June values. The arithmetic mean flows for the first ½ of January 2002 was a remarkably high 1285 CFS[2] peaking on January 7th (also one of our sampling dates). Spring and summer river discharges were relatively normal in 2002. These conditions must be kept in mind throughout the entire analysis (see appendix C for details).

Generally about ½ of the entire river flow enters the Inner Bay if we consider that at steady state flood tides occur about half of the time. As the river mouth is located outside the entry to the Inner Bay by >1 km, and west winds are more prevalent on an annual basis than east winds, I reduced the estimated volume of river water thought to enter the Inner Bay to 45% of the total discharge.

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[2] Several Aspects of Dungeness River Flow History, unpublished report by Welden Clark dated 1/22/03

For estimation of the annual water budget of the study year (water year 2002) the river discharged a volume of 415 million cubic meters, with 45% or 186.8 million cubic meters of river water entering the Inner Bay directly on flood tides. This compared similarly to the phase 1 study year of 2000 when the total discharge was 431 million cubic meters, although that was a calendar year. For water year 2002 on an annual basis:

Equation 6. River Inflow to Inner Bay = $(0.45)(13.2\ m^3/s)(31.536\text{x}10^6\ s/yr) = 187\text{x}10^6\ m^3/yr$

This is a simplification, as some of the river water washed away from the river mouth to the east during ebb tide later re-enters the Inner Bay due to reflux. However, that will be dealt with in the fecal coliform budget using real measurements as explained later.

6.3 Marine Inflow

The next component needed is “marine inflow” which is a subset of tidal inflow. By definition, it is tidal inflow minus river inflow to the Inner Bay during flood tide and is a mathematical construct but nevertheless reasonably accurate and needed later in the fecal coliform budget. For the study year marine inflow is:

Equation 7. Marine inflow = Tidal inflow – (0.45 x Total River Flow)

$= 4.61\text{x}10^9\ m^3/yr - 1.87\ \text{x}10^8\ m^3/yr = 4.42\text{x}10^9\ m^3/yr$

6.4 Direct Precipitation and Evaporation

Due to the large size and range of elevations within the Dungeness Bay watershed, the area’s rainfall amounts vary enormously. This does not pose a computational problem for the water budget, however, because virtually the entire catchment area is tributary to the Dungeness River, and its flow rates were measured at the Department of Ecology gauging station. Only a relatively small area directly discharges to the Bay and this was accounted for below in the ditch inflow measurements.

Previously the average annual rainfall for this area was shown to be 427 mm per year (16.9 inches, phase 1 report). Given the Bay surface area of 5.61 km^2 and multiplied by the water year 2002 rainfall total of 335 mm (13.9 inches, measured in nearby Sequim), the direct precipitation onto the Inner Bay was 1.88 million cubic meters per year. For the study year this is computed as:

Equation 8. Direct Inner Bay precipitation = 5.61 km2 x 335 mm = $1.88\ \text{x}\ 10^6\ m^3/yr$

The study tear water budget accounts for rainfall by season that included Nov-Feb (185.7 mm), Mar-July (110 mm) and Aug-Oct (39.1 mm).

Estimated evaporation rates for Sequim (Source: Western Regional Climate Center, Reno, NV) are 40.4 cm/yr for Actual Evapotranspiration from a 6-inch Waterholding Capacity Soil (Ea[6]), and 61.7 cm/yr for Potential Evapotranspiration (PET). Annual evaporative water losses rates from Inner Dungeness Bay are anticipated to be reasonably approximated by Ea[6]. This Ea[6] of 40.4 cm/yr is very close to the estimated pan evaporation times a pan coefficient of 0.6 that yields a water surface evaporation of 41.1 cm/yr (Dunne and Leopold 1978). Multiplying Bay surface area by evaporative loss rate yields:

Equation 9. Annual evaporative loss = 5.61 km^2 x 40.4 cm/yr = 2,300,000 m^3/yr

6.5 Stormwater Inflow

Stormwater enters the Inner Bay directly via the irrigation ditch outfalls and possibly via a very small, apparently seasonal-flowing creek known as Railway Creek at the far western end of the Inner Bay. Stormwater that discharges into the river need not be considered here because it is already quantified in the river water budget component. In the phase 1 portion of this project the total stormwater flow directly to the Inner Bay was estimated to be ~ 10,000 m^3/yr. As the actual measured irrigation ditch flows exceed this value by nearly two orders of magnitude, I will opt not to include this component in the water or fecal coliform budget. Essentially it is already accounted for in the next section.

6.6 Irrigation Ditch Inflow

Approximately 270 km of irrigation ditches are reported to exist in the Dungeness Bay watershed. Water is diverted from the Dungeness River beginning at about RM11.2 into this system of ditches and pipes. The irrigation ditches then discharge return flow back into the Dungeness River and its tributaries further downstream. Because of their widespread use, the irrigation ditches also convey stormwater and, presumably, water from failing septic systems. A fairly small portion of the irrigation ditches in the watershed discharge directly into Dungeness Bay. These discharge via about seven outfall pipes located along the southern shore of the Inner Bay. We collected periodic measurements of all ditches observed to be flowing and found average flows by season to be 11.3, 11.0 and 7.9 L/s (Appendix D).

Equation 10. Irrigation Return Flow = (0.037 m^3/s)(214 d/yr)(86,400 s/d) = 684,000 m^3/yr

6.7 Groundwater

Groundwater has not been analyzed as part of this study. However, available literature and our field observations lead us to believe that only minor groundwater flow may enter the Inner Bay from the mainland, and no appreciable groundwater flow is expected to enter from along the spits due to their narrow shape. While walking along the beach near the toe of the bluff during minus tides, only very minor flow was seen to emerge from mud, sand or gravel beach areas. This was located near the irrigation ditch that flows into the Inner Bay nearest the Cline Spit boat ramp. Three literature sources were reviewed with regard to possible groundwater flow into the Inner bay. Several sections are paraphrased or are near quotes but parenthetical notation is neglected.

Drost, (1983) conducted an extensive survey and groundwater steady state flow model for the subject area in March 1979 when precipitation was minimal, groundwater levels stable, flow in the Dungeness River constant, evapotranspiration minimal, and although flow was occurring in irrigation ditches, no field irrigation was ongoing. Calibration was contingent on holding these factors constant to allow for modeling of hydraulic conductivity of the water-table aquifer, transmissivity, vertical leakage and river leakage. Varying of the vertical leakage coefficients was found not to affect the model and river leakage coefficients were adjusted to obtain the best reproduction of heads in the water-table aquifer and measured leakage. Calibration of the model was checked by measured and modeled components individually.

The water budget for March 1979, calculated from the model of the ground-water system for the subject area is shown below as Figure 25, extracted from Drost (1983). The primary interest in this figure is the shallow water table output (on the left) to saltwater bodies of 40.8

CFS. Using a planometer, I estimated that about 12% of the length of the entire subject salt water shoreline is accounted for by inner Dungeness Bay. Assuming equal distribution of flow along the entire shoreline the irrigation season inflow would be about 5 CFS or about 4.5 x 10^6 m^3/yr conservatively assuming the flow was year round. While not trivial, this volume is not significant compared to marine water inflow and river flow.

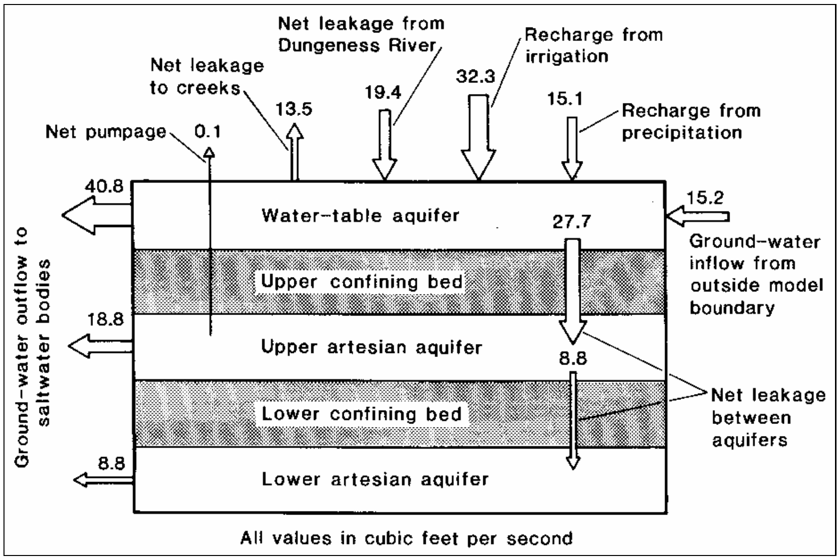

Figure 25. March 1979 groundwater budged for subject area (Drost 1983).

While Drost did not investigate the location of groundwater discharge from the water-table aquifer to saltwater, it is reasonable to assume (because of the shallowness of the Inner Bay relative to the depth of the aquifer) that the majority of that discharge actually occurs downgradient (northward) of Dungeness Spit. In 1983, roughly 40% of recharge to the water-table aquifer was attributable to irrigation leakage; the relative percent now is no doubt much lower than that due to changes in land use and conservation improvements – meaning that outflow from the entire system is lower now.

The accuracy of the Drost model may not be great, but its importance here is to show that the volume of ground water inflow is trivial compared to the huge values of inflow for the marine water and to a lesser extent, the river water. The amount of groundwater inflow to the Bay is of the same order of magnitude as direct precipitation. Given the data in the Drost report, it is not possible to segment out different areas of the marine shoreline into high versus low groundwater yielding areas.

A second report, Drost 1986, was prepared as a data report to document existing conditions in the county, and involves the study of water quality and quantities and identification of problem areas (e.g., salt water intrusion zones) but no budget for ground water was developed. There were no data or data summaries for fecal coliform or total coliform for groundwater.

A third and more recent report (Thomas et al. 1999) involves more recent analysis of the Sequim-Dungeness area in the mid 1990s. Surface and ground water quality, quantity and coupling are examined. There are many interesting data and observations (including discharge measurements of an irrigation ditch return that flows into the inner bay), but the purpose and scope did not include an explicit examination of ground water loss to salt water bodies. They did note that their estimated total groundwater discharge for the entire Sequim-Dungeness study area was 43% of the total discharge (i.e., .43 x 151 CFS ~ 65 CFS, in agreement with the prior estimate). The report states that the data may be used in developing a new groundwater flow model, but at present the model is under construction (A. Soule, pers. comm. 2002). This report presents more detail about the depth to differing groundwater strata, the direction of flow (South to North in all cases), and other pertinent details.

Of some interest in the present context are estimates of shallower aquifer thickness (their Fig. 18) that shows a thick area around and to either side of Cline Spit that range from 151 to 250 feet deep. This is far deeper than any part of the Inner Bay and hence much of this aquifer probably flows beneath the bay to exit in the deepwater of the Strait of Juan de Fuca north of the main spit. The horizontal hydraulic conductivity (i.e., the relative speed of lateral flow) is quite high near Dungeness Bay compared to other areas, with a median value of 150 feet per day (Their Fig. 26) compared to an overall median value of 70 feet per day for the entire shallow aquifer. In the discharge section (page 75+) the authors note that discharge to springs is probably small compared with the sum of subsurface flow to saltwater bodies and flow to streams, although there may be exceptions in isolated areas. The recharge section of the report shows small areas of Graveyard Spit and the main spit near the lighthouse as recharge zone from precipitation. Probably some of this inflow becomes interflow and flows to the marine waters as beach seeps or shallow, subtidal inflow, but the volume is apparently minimal.

Collectively, our observations and the available literature support neglecting groundwater inflow to the Inner Bay as acceptable and logical. No available evidence was found to support any other position. The most probable case is that groundwater inflow to the bay is absent of fecal coliform content and is therefore a very minor diluting factor, highly insignificant in the overall water budget.

6.8 Tidal Outflow

Tidal outflow from the Inner Bay is a composite of several previously calculated water budget components which may be described as:

Equation 11. Tidal outflow = tidal inflow + irrigation inflow + direct precipitation - evaporation

This calculation should provide a reasonably accurate measure for a long term period such as a lunar tidal cycle or longer. Tidal outflow for the study year was calculated to be 4.60×10^9

6.9 Salt Budget

As salinity of seawater is a conservative tracer, we may use the proportion of seawater to river water in the inner bay as an estimator of the influence of the Inner Bay. A salt balance calculation reveals the percentage of salt and fresh water in the Bay. Special care was taken to calibrate the salinity probe frequently and using quality standards from the University of Washington. The percent Dungeness River water in the bay may be calculated from data in Table 11 and equation 12.

In all cases offshore salinity remained about 31 psu or greater increasing in the late summer and fall with the reduction of river flow from major rivers such as the Fraser and Skagit Rivers. However, considerable seasonal variation was seen at the Entry Zone and inner bay. Of particular interest was the winter season when inner bay salinity was depressed significantly compared to the offshore station by 15.6%. This reflects the unusually great river flow during that season in 2002 and perhaps the tendency of the east winds to push the river plume further into the inner bay than would occur at other time.

Table 11. Seasonal salinity concentrations (psu) integrated from near surface and subsurface over 3 to 5 m at offshore, Entry Zone and inner bay stations.

Season	Parameter	Offshore Station	Inner Bay Stations	Percent Freshwater
Nov-Feb	**Salinity**	**31.12**	**26.26**	**15.6%**
	N	9	38	
Mar-July	**Salinity**	**30.92**	**28.96**	**6.3%**
	N	18	54	
Aug-Oct	**Salinity**	**31.83**	**30.70**	**3.6%**
	N	8	28	
Annual*	**Salinity**	**31.29**	**28.64**	**8.7%***

*Annual mean weighted for unequal number of days in seasons.

Equation 12. Percent River water in Inner Bay = (100)(offshore sal.-inshore sal.) / offshore sal.

After accounting for unequal time periods for the seasons in Table 11, the inner bay was comprised of 8.7% Dungeness River water and 91.3% Strait of Juan de Fuca water. By season it varied from 15.6% in Nov-Feb to only 3.6% in Aug-Oct seasons. These values can not be compared with the percent river water shown in the water budget, as that value reports only the first flood tide river water component not that involved with Inner Bay reflux. The difference between the two (8.7% salinity measured minus 4.1% estimated river inflow = 4.6% difference) must be due to reflux in a steady state. Given the estimated reflux of 45%, the difference can be rationalized (0.45 x 8.7 = 3.9% ~ 4.6%). If the river flowed directly into the Inner Bay a flushing rate estimate using salinity differences could be prepared. That was not attempted for this report due to the complexity of river flow entering the Outer Bay which is not the target of the modeling herein.

6.10 Water Budget Summary

Annual flux of water through Inner Dungeness Bay is comprised of tidal inflow which was partitioned into Dungeness River flow and marine water inflow. Other sources of water include irrigation ditch returns and direct precipitation (Table 12). Relatively little groundwater is believed to enter the Bay. Again, the river discharge to the Inner Bay contains contributions of irrigation return flow, stormwater and other pollutant sources, but for the purposes of this study these are all considered to be part of the river flow.

Study year flux of the various water sources shown in Table 12 indicates that marine water is by far the largest inflow, about 96% of total. River inflow, at 4.1% is the second major inflow, but it is emphasized that this does not include refluxed river discharge. Direct precipitation, irrigation return flow and direct stormwater inflow were all less than 0.1 percent of the total inflow. These values represent are similar to the long term averages calculated for the phase 1 report, as intertidal volume estimates were correct despite errors in the total volume calculations.

Outflow from the Inner Bay is dominated by tidal flow, which accounts for 99.95% of the water lost. Evaporative losses are minor at about 0.05% of the total. No other water losses have been identified. Seasonal values for each of these factors are omitted here for brevity and the necessity of weighting the results for a common time unit within a season.

Table 12. Annual water inflow and outflow by component to Inner Dungeness Bay during the study year October 2001-September 2002.

Water Inflow – Outflow & Source	Volume (m^3/y)	Fraction (%)
Inflow to the Inner Bay		
Marine Water*	4,420,000,000	95.89%
Dungeness River Water	187,000,000	4.06%
Direct Precipitation	1,880,000	0.04%
Direct Irrigation Return Flow	684,000	0.01%
Total Inflow	**4,609,564,000**	**100%**
Outflow from the Inner Bay		
Tidal Outflow	4,605,384,000	99.95%
Evaporation	2,300,000	0.05%
Total Outflow	**4,609,564,000**	**100%**

* Marine water includes refluxed Inner Bay water and refluxed river water not accounted for separately.

7 FECAL COLIFORM LOADING ESTIMATE FOR INNER BAY

An estimate of the study year annual and seasonal fecal coliform loading is presented in this chapter. This is not a true mass balance model, as some factors are not known with great accuracy. Nevertheless, there is enough information to reach first order conclusions regarding seasonal sources and sinks of FC. The budget is a product of the stated water budget components multiplied by the arithmetic mean FC concentrations for certain subareas and times. I considered using geometric mean FC concentrations in this analysis, as well as median values, but decided upon the arithmetic mean instead. Several reasons were involved in this choice including the facts that:

- The arithmetic means represents the true middle point of a normally-distributed data distribution.
- Very few really large bacterial results were encountered from the primary and other selected data stations, negating the need for the smoothing effect of the geometric mean[3].
- The Dungeness River TMDL study (Sargeant 2002) had used that arithmetic means.
- Phase 1 study analysis of river mouth data collected by DOH indicated that variations of the arithmetic mean corresponded closely (r = 0.99) with the 90th percentile FC values (Fig. 26). Other measures such as the median were not closely related. Because shellfish harvesting closures and water quality violations in Dungeness Bay typically involve the 90th percentile standard, the choice of the arithmetic mean was all the more attractive for load estimates.

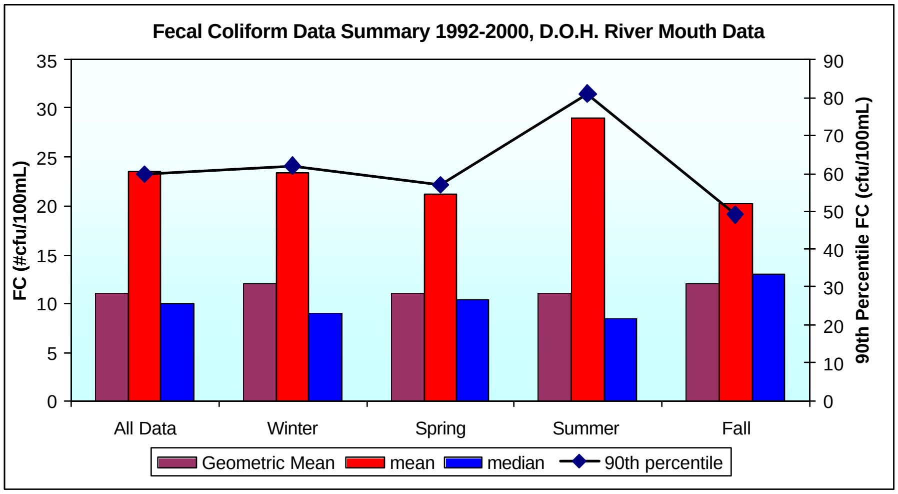

Figure 26. Summary of Department of Health 1992-2000 Dungeness River mouth fecal coliform data using different statistical measures of annual over calendar seasons.

There are two main components of the fecal coliform analysis presented here:

1) **An input – output component** from measurements taken at the Entry Zone to the Inner Bay. That location was sampled more frequently than other locations. The resulting imbalance

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[3] Specialized sampling, such extremely near the seal haul out at Cline Spit Island had large FC hits, but these were not used in the model as they were non-random and represented only a very small portion of the water masses flow through the nearby channels. See the Wildlife section for more detail.

of measured input and output loads are then used to estimate if Inner Bay or Outer Bay-Riverine sources are dominant within a given season.

2) **Individual source loading estimates** of Inner Bay and Outer Bay sources of FC with no attempt to quantitatively estimate transport, dilution or die off factors. Those factors are, however, considered semi-quantitatively as our knowledge of transport, vertical stratification, light, temperature and other factors is sufficient to address these issues in a general sense.

Aspects of the fecal coliform loading estimation include:

- Steady state condition, i.e., over a lunar tidal cycle and within a season, the system operates without much variation. This of course is not entirely true, but for the purposes of this first order model, it is a reasonable approximation.
- An accounting of Inner Bay FC loading, using measured riverine discharge and FC data (at the river mouth), measured irrigation ditch flow and FC data, estimated wildlife loading from the product of periodic abundance counts and literature production rates.
- Application of FC availability factors to different taxa of wildlife in the Inner Bay to account for difference in solubility and transport.
- Use of river mouth FC data with and without the presence of the large number of gulls frequently found there.
- Representation of surface and subsurface conditions in all assayed marine waters. Virtually all other FC studies focus only on surface waters, and for Inner Dungeness Bay this would have been a major omission for the critical winter season.
- Selection of data sets appropriate for the model based on the knowledge of bay circulation obtained in the Phase 1 study, i.e., that the river almost always enters the Inner Bay near the south, shallow side of the Entry Zone, so the north, deep side of the channel was sampled to represent marine water FC content entering the Inner Bay.
- Application of sensitivity analysis to explore the possible range of solutions

Again, the reader is forewarned that inputs do not equal outputs (as must necessarily be true using over a relatively long period of time) but the computation is presented as best-available-estimates. Factors that are not known with great accuracy include bacterial die off rate, wildlife FC production and "availability", and transport and tidal excursion rates of certain subareas. As discussed below, only one of these (wildlife FC production) is potentially highly variable which allows us to solve for one unknown in a general model.

Four components of the load estimate model are next considered: 1) marine inflow that includes all outer bay factors except the river flow, 2) riverine inflow or ~ ½ the total load of the Dungeness River as measured at the river mouth and 3) Tidal inflow, the difference of 1 and 2 above, and 4) Outflow from the Inner Bay.

7.1 Marine Water Inflow

By definition "marine water inflow" is further defined as: 1) Strait of Juan de Fuca water flowing into the Inner Bay and 2) Dungeness River water that entered Outer Dungeness Bay on an ebb tide but returned on subsequent flood tides and 3) Inner Bay reflux water that flows out of the Inner Bay to be later recycled back into the Inner Bay on a subsequent flood tide.

It is not possible to accurately separate the relative contributions of these sources given available resources but we know with certainty that the Strait of Juan de Fuca water is an important component, based on the high salinity and relatively low FC load of inflowing water as discussed below. It is also safe to assume that reflux of Inner Bay water accounts for a very significant portion of marine inflow, given the estimated reflux rate of 45% and the high outflow of FC load especially in the winter, as discussed below in section 7.4.

River water volume contribution is dwarfed by marine water volume entering the Inner Bay. With no observed exceptions the direct, flood tide inflow of river water into the Inner Bay was restricted to the shallow, south side of the Entry Zone channel as observed and documented by salinity and drogue measurements in both phases of this study. Accordingly, a sampling regime was established to measure the "marine" water inflow FC concentrations in the north, deep end of the entry channel that had the most volume as evidenced by faster flows and greater depths than other parts of the channel.

Table 13. Summary of marine inflow fecal coliform load analysis including surface and subsurface waters during flood tide from the Inner Bay Entry Zone and nearby Outer Bay stations.

Marine Inflow*	1 (Nov-Feb)	2 (Mar-July)	3 (Aug-Oct)
Arithmetic mean FC (#/100ml)	**4.8****	**2.0**	**1.4**
Number of samples	26	32	37
Coefficient of variation	1.1	1.1	1.7
Mean salinity (psu)	30.2	30.7	30.3
Volume (m^3/d)	1.26×10^7	1.26×10^7	1.26×10^7
Estimated Load (FC/day)	6.06×10^{11}	2.52×10^{11}	1.77×10^{11}
Strait*** mean salinity (psu)	31.1	30.9	31.8

* See definition in the text.
** >4 per 100 ml if January 7th major flooding event data excluded.
*** Strait of Juan de Fuca salinity for comparison to illustrate effect of ebb tide river water that returns from Outer Bay to enter Inner Bay.

Fecal coliform content of the marine water was determined from surface and subsurface measurements at the Entry Zone to Inner Dungeness Bay during flood tide. With the exception of January 2002 during a large river flood event, the results showed high salinity content at both depths. These Entry Zone data were supplemented with nearby Outer Bay data to bolster sample size. These Outer Bay samples were taken within the main channel or approximate center of the outer bay, areas that are within the average tidal excursion distance from the entry channel. The compilation specifically excludes any river mouth or near river mouth samples, as determined by salinity measurements and visual observations. Northern Outer Bay samples were not included based on drogue survey results that showed clockwise (out of bay) gyre motion during flood tide. Table 13 summarizes the FC data used for this portion of the analysis.

Average fecal coliform concentration was greater during the November to February season, declined greatly during the spring and early summer and was lowest for the late summer early fall period. Most of the Outer Bay was turbid and replete with flotsam during the January 2002 sampling event that coincided almost exactly with peak river flows. Tidal amplitude was moderately high at this time and several FC results, both surface and subsurface, were elevated despite salinity measurements that were >25 psu. Accordingly, these values were retained for the model but this point is useful to stress that the mass balance model reported in this report is for the specific water year encountered, and would be somewhat different for other years where winter river flow was relatively normal. In other words, the study year was a worse case analysis for river effect.

7.2 Riverine Inflow

Riverine FC load to the Inner Bay is composed of two major components, the direct flow during flood tide and the indirect flow that involves reflux of ebb tide river flow. The latter was included in the above section, the former is discussed here. Fecal coliform load of the river contributes to Inner Bay during flood tide periods which occur on average 45% (not to be confused with the 45% Inner Bay reflux rate) of the time as previously explained in the water budget. Data for this estimate were taken directly from the river mouth, rather than at the Inner Bay Entry Zone. At high tide this meant motoring the sampling boat up past the point of MHHW. At extreme low tide the sampling station was far to the north, after the river had traveled a long distance across the sand flats.

Some data were collected from south side of Inner Bay entry channel, and on many occasions we noted lower salinity and higher FC at surface, verifying that the river was flowing through that area. However, the river plume was not easily located every sampling day and there wasn't time for extensive searching, so the mass balance model used herein does not rely on the south entry channel data to estimate river loading.

Only the shallow surface layer (0.05 or 0.1 m depth) data were used in this estimate, as it was found that subsurface samples, even if only ~ 0.2 m or often less depth, was composed of relatively high salinity marine waters, typically of much lower FC content. To include averages of surface and subsurface data would have resulted in a reduced FC concentration and loads that were not appropriate for the calculation. On several calm weather occasions we were able to document the location of the river plume by salinity measurements. This showed that the plume remained extremely thin, much thinner than would be properly sampled by the usual wrist-deep method used for shellfish regulatory work. On a calm day in the fall of 2001 at slack tide we traced the river plume that flowed across the Outer Bay to the east side of Graveyard Spit. Concurrent FC measurement indicated that the plume was transporting the bacteria across the bay at that time too.

Data were collected during all tidal phases, but as previously mentioned, there was seasonal bias of sampling due to normal tidal variation, for example at low tides during the day in springtime and part of the summer. At that time numerous birds, especially gulls but also occasionally geese, ducks and others were present in the river channel as it flowed over the sand flats. This allowed the direct measurement of the effect of the birds, by sampling above and downstream of them. See the Wildlife section of this chapter for a discussion of how I accounted for high tide periods and periods when the birds were not as abundant and balanced the type of data used.

Table 14 indicates that the Dungeness River during Nov-Feb and March to July periods had similar mean daily loading rates. The Aug–Oct season had higher average concentrations, but lower loading because of lower volumetric discharge. The high spring and early summer results were attributable in part to the presence of very large numbers of gulls at the river mouth, as discussed later in this report. The adverse effects of the large spring and early summer FC loading is mitigated by warmer water and increased levels of sunlight, both key factors that cause FC die off. The estimates shown here are at the point of production, and by the time the river flows into the inner bay an unknown but probably not trivial amount of die off occurs. This is shown experimentally as both north and south stations at the Entry Zone to the Inner Bay showed no increase during spring. As also shown later, inflowing FC loading in the spring and early summer to the Inner Bay exceeded outflow so the riverine effect was not insignificant.

Table 14. Summary of Dungeness River fecal coliform inflow data used in load analysis that includes surface sampling results (<0.2 m) only.

Riverine Inflow Parameter	1 (Nov-Feb)	2 (Mar-July)	3 (Aug-Oct)
Arithmetic mean FC (#/100ml)	**15.6**	**21.0***	**24.1***
Number of surface samples	8	41	18
Coefficient of variation	1.0	0.9	0.5
Mean salinity (psu)	12.4	3.3	6.3
Estimated Load (FC/day)	5.68×10^{10}	6.00×10^{10}	1.72×10^{10}

* Estimates explained in the Wildlife section of this chapter.

Another aspect of these data involves the salinity content. As there is a moderate to strong inverse correlation between salinity and FC concentration at the river mouth and other areas in the bay, note that each season had a differing mean salinity result. The winter season had the highest percent salinity and thus it is possible that the FC estimate for this season is about 30% low. Spring and early summer mean salinity was close to freshwater (3.3 psu) so only a small correction factor to the FC result could be applied. Late summer and early fall's result was intermediate between the former two. However, I choose not to apply a correction factor as doing so would ignore the fact that other sources of FC in this area are not tied directly to freshwater, i.e., bird fecal loads. See section 7.8 for further discussion of river loading, correlations and comparison to wildlife sources.

7.3 Tidal Inflow

Tidal inflow is the composite of riverine inflow and marine water inflow, compiled from observed data discussed above. I defer the accounting here to the summary section.

7.4 Tidal Outflow from Inner Bay

Tidal outflow FC load was calculated from measured concentrations on ebb tide at the entry zone to the Inner Bay multiplied by the water volume transport. From the phase 1 conceptual model and confirming observations, it was assumed that the river load, minus die off, would be accounted for in the main entry channel observations on ebb tide. Inspection of ebb tide vertical profiles at this point showed this to be true. Tidal outflow in the phase 1 model included several other components and all Inner Bay station FC data, but our knowledge of average tidal excursion suggests that much of the western Inner Bay does not flush completely on an average tidal exchange.

Similarly, convergence and Cline Spit gyre areas may be slowly flushed, so the only data justified to be used for this component were observations from water actually leaving the Inner Bay as shown in Table 15.

Table 15. Summary of Inner Bay outflow fecal coliform data used in load analysis that includes surface and subsurface results.

Inner Bay outflow	1 (Nov-Feb)	2 (Mar-July)	3 (Aug-Oct)
Arithmetic mean FC (#/100ml)	**11.2**	**2.2**	**1.6**
Number of observations	36	32	11
Coefficient of variation	1.1	1.0	0.9
Mean salinity (psu)	29.0	29.0	31.5
Estimated Load (FC/day)	1.41×10^{12}	2.77×10^{11}	2.02×10^{11}

7.5 Inflow versus Outflow Loads

Daily tidal inflow and outflow FC loads from the Inner Bay by season are shown in Figure 27. These are simply from measured FC concentrations and estimated flows and therefore account for internal and external sources, as delivered to the Entry Zone threshold to the Inner Bay. The comparison is useful to examine seasonal imbalances that point to external or internal dominating FC sources. Inner Bay sources appear to dominate by 41% in the (Nov-Feb) period while Outer Bay sources seem to slightly dominate at other times.

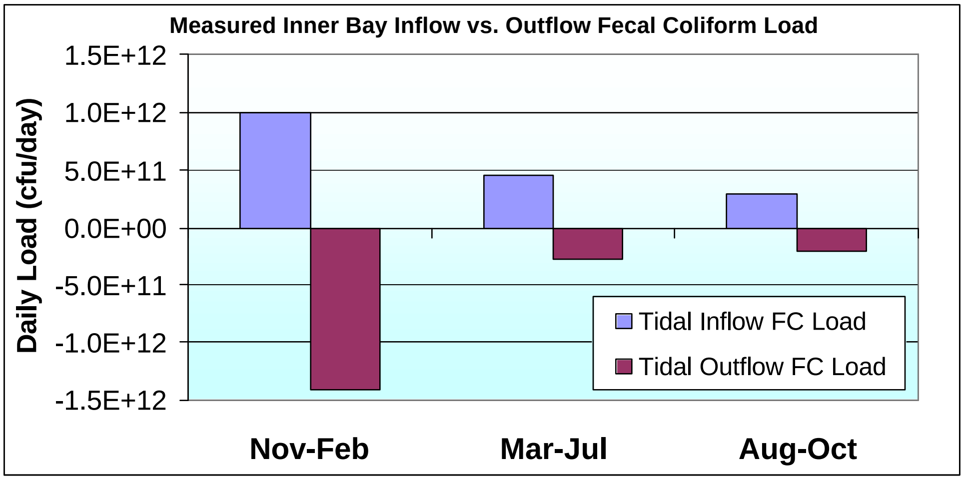

Figure 27. Measured Inner Bay inflow versus outflow of fecal coliform loading by season.

The imbalances of input and output were expected and do not necessarily relate to measurement error or accuracy. Rather they likely reflect greater production, survival and transport of FC bacteria in or out of the Inner Bay within the given seasons. These data are rationalized further throughout the remainder of this chapter.

7.6 Irrigation Ditch Inflow

Seven irrigation ditch returns or other water conduits that flow to the south shore of the Inner Bay were identified and periodically measured during the study year (Table 16, see Appendix D for concentrations). These ditches frequently had very high fecal coliform concentrations that are apparently influencing DOH sampling results (Table 16). A total of 104 samples were collected including duplicates and within-single-day replicates. The returns are labeled 1 through 7 and are in order from east to west. Outlet number 6 was not observed flowing during this study. Only three of the ditches had substantial flow and FC loads. Ditch number 1 was nearest the Cline Spit boat launch, ditch 4 was near a small red boathouse and ditch 7 was furthest to the east and referred to as the “rock water fall”.

Table 16. Mean discharge (L/s), Geometric mean and 90th percentile (cfu/100 ml) and fecal coliform loading (cfu per season or day as indicated) of irrigation ditch returns from south shore of Inner Dungeness Bay, October 2001 to September 2002.

	Irrigation Ditch Return Number						
DISCHARGE	**1**	**2**	**3**	**4**	**5**	**7**	**Sum**
Nov-Feb	1.7	2.4	0	1.8	0	5.3	11.3
Mar-July	5.1	1.9	0.8	0.8	0.5	1.9	12.2
Aug-Oct	4.0	0.0	0	1.1	0.5	2.3	7.9
Mean	3.6	1.4	0.3	1.3	0.3	3.2	
Percent of Annual Volume	36%	14%	3%	12%	3%	32%	
Geometric Mean FC	**1**	**2**	**3**	**4**	**5**	**7**	
Nov-Feb	127	87	-	117	-	128	
Mar-July	27	91	108	47	21	41	
Aug-Oct	130	-	-	96	14	177	
90th Percentile Fecal Coliform	**1**	**2**	**3**	**4**	**5**	**7**	
Nov-Feb	3,071	87	-	4,264	-	3,256	
Mar-July	109	154	480	1,782	262	567	
Aug-Oct	639	-	-	155	16	343	
FC LOAD*	**1**	**2**	**3**	**4**	**5**	**7**	**Daily Loading***
Nov-Feb	8.09 x10^{11}	2.35 x10^{11}	0	8.77 x10^{11}	0	1.44 x10^{12}	2.80 x10^{10}
Mar-July	4.33 x10^{11}	1.60 x10^{10}	1.56 x10^{10}	3.83 x10^{10}	5.98 x10^{9}	2.50 x10^{10}	9.43 x10^{8}
Aug-Oct	4.15 x10^{9}	0	0	6.46 x10^{8}	3.62 x10^{7}	2.77 x10^{9}	8.27 x10^{7}
Sum	8.56 x10^{11}	2.51 x10^{11}	1.56 x10^{10}	9.16 x10^{11}	6.01 x10^{9}	1.46 x10^{12}	
Percent of Annual Load	24%	7.2%	0.4%	26.1%	0.2%	41.7%	

* seasonal units are cfu/season ** Daily loading units are cfu/day for each season for all ditches

The irrigation ditch load as given above is the product of total annual flow times the geometric mean FC concentration. As sampling was conducted year round, it includes storm flows so no additional factor is added on that account (Table 17). Although total discharge for all ditch outfalls combined was somewhat constant through all seasons, FC concentrations were not and hence neither were the total load estimates. Maximum contribution of the ditch outfalls was during the winter months of November through February. Previously from the phase 1 report it was thought that irrigation ditch returns to the Inner Bay were insignificant in the total FC budget accounting for only 0.6% of the annual load. As will be seen in the final accounting and mass balance later in this chapter, the irrigation ditches are a significant source in the winter and contributed fully 6% of the Inner Bay load. During the intense rains and flooding of early January 2002 all four of the primary contributing ditches had FC concentrations > 1500 and a median result of 4400 cfu/100ml.

In the other seasons, the total load from these irrigation ditches is very low compared to other sources, but the concentration of FC remains fairly high. The DOH samples nearshore and nearby several of the irrigation ditch returns. DOH stations 110 and 111 are likely to detect FC from the irrigation ditches as the freshwater flows over the surface of the salt water and sampling is often done near high tide, which increases proximity to the sources and reduces the chance of dilution.

Table 17. Seasonal and mean daily load of all irrigation ditch outfalls during the study year, October 2001 through September 2002.

Season	Seasonal Load	No. of days per Season	Mean daily load per season	Relative % Daily Load per season
Nov-Feb	3.36E+12	120	2.80E+10	96.5%
Mar-July	1.44E+11	153	9.43E+08	3.3%
Aug-Oct	7.61E+09	92	8.27E+07	0.3%

7.7 Direct Precipitation and Evaporation

These factors do not contribute or remove FC from the Bay. Precipitation that falls on the land and becomes stormwater is modeled separately.

7.8 Birds and Seals

Wildlife use of Dungeness Bay is a complex subject, as there are large variations among species use patterns for short and long time scales. Foremost to keep in mind is that a large part of Dungeness Bay is a national wildlife refuge, i.e., these animals certainly have a right to use this area and nothing in this report is intended to indicate otherwise. However, there is no reason to exclude wildlife from scrutiny as possible sources of fecal coliform.

Some important aspects of the bird and marine mammal use of the bay can be briefly summarized[4] as follows: Dungeness Bay is an important winter migration and feeding area for waterfowl. In terms of biomass and high relative abundance, Brant are often very abundant in winter and spring while several types of ducks including American Widgeon, Mallards, and Northern Pintail are abundant during fall and winter. Canada Geese and Double-crested Cormorant are common year round while Pelagic Cormorant are common in all but spring. Glaucous-winged/Western Gulls are abundant year round, either in the refuge itself or across the bay near the river mouth and on Cline Spit Island or nearby. Many other types of birds are common or present in Dungeness Bay at certain times of the year as listed by USFWS (2002).

Previous Analysis of Wildlife Effects: Total bird and seal counts during the May to September 2000 phase 1 study were approximately similar each sampling day, but that study

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[4] The phase 1 report cites formal sources of background information not repeated here. The present analysis also utilizes more recent information including discussions and emails with Pam Sanguinetti of the USFWS Dungeness Wildlife Refuge staff as well as the Refuge Wildlife Checklist (2002) which offer very useful relative abundance summaries by season.

did not include the fall through spring seasons. The prior report discussed the relatively large source of FC that the birds and seals represent, but in calculating FC loads discounted the effects of wildlife based on anecdotal observations and comparison to other studies (some that had also anecdotally dismissed wildlife as a significant source of FC to affected areas). The primary reason for discounting wildlife involved sinking of fecal pellets out of the surface water, which reportedly reduced contributions. Later in this report I present evidence that this was probably an invalid assumption for at least ducks and gulls that contribute significantly to Dungeness Bay FC loads. Dungeness Bay is quite shallow, and resuspension of wastes are likely in the more tidally active areas.

A secondary reason for discounting wildlife effects involved our review of the results of a separate Tribal/State study conducted over 13 hours on September 17, 2000 near the river mouth and upstream at river mile 0.2 with many birds present at the river mouth. In reviewing those data again, I note several problems with that study that would not have been apparent earlier, given our state of knowledge:

1) Bacterial die off occurs in the lower river downstream of the sampling area that was used

2) Background FC concentrations at the in-river station ranged from low to high (up to 80 fcu/100ml) and there was no extensive replicate sampling.

3) River mouth sampling reported herein often shows that the freshwater river plume is too shallow to be properly sampled by the normal, “wrist-deep” FC sampling procedure. However, the apparent intent of the study was to sample the plume.

4) A refractometer that measures a single drop of water from an undetermined depth dripping off the wrist deep sample was used as an index of salinity for the downstream samples. As far as I could determine, as I was on site on that day doing other sampling, no attempt was made to locate the sampling boat in the middle of the actual river plume. Some of the downstream samples could have easily been drawn more from marine water fluxing in and out of the Inner Bay and the salinity results reflect it.

5) Tidal level was relatively high most of that particular sampling day ranging from 6.2 to 2.8 back up to 7.0 feet. As discussed below, I found it necessary to have tidal level below about 1 to 2 feet (MLLW) to detect a major bird effect (and by that point only gulls and sometimes some geese remained). When the tidal level is relatively low, the river flows within several distinct or braided channels across the sand flats and one can effectively sample upstream and downstream of a known number of birds.

It has been my experience in conducting dozens of upstream/downstream analysis to measure nutrient production of salmon pens that it is very difficult to find conditions in marine waters that approximate laminar flow. If drogues are used, the chances of success are much higher, but vertical mixing and vertical dispersion are still unaccounted for in such an approach. Collectively, I must disregard the results of the previous Tribal/State study for all the reasons mentioned above.

Bird and Seal Population Estimates 2001-2002: Counts of large bodied birds and harbor seals during the study year were derived from three types of counts that were melded together for the Inner Bay and the River Mouth area to the old pier near Three Crabs area. The surveys included:

1) Counts from the Bluff at one of several locations overlooking the bay on the high bluff along the south side of the bay. Dr. Ralph Elston performed these counts using a high quality spotting telescope and estimated all birds and seals present within subareas of the Inner Bay to the River Mouth from March to October 2002.

2) Boat-based counts were made during all sampling events from the sampling boat, but these counts were principally restricted to large bodied birds and seals, and small birds such as shore birds were neglected due to time constraints

3) Land-based counts from Dungeness Spit were made by Pam Sanguinetti (USFWS) as part of her regular sampling efforts, but these counts did not include River Mouth areas. Her counts were the primary source of duck, cormorant and geese data for the October through March period.

The results of these surveys are summarized in Table 18 as monthly mean population estimates, by taxa and subarea, drawn from a total of 22 daily observations (average of 1.8 per month). Small body birds such as shorebirds and occasional other large birds such as blue-herons were counted too, but not included in this summary as their effect was judged too minor to be included due to their scant numbers or marginal location in shallows or shore areas. Gulls, ducks and geese are specifically singled out here as the literature (e.g., Weiskel et al. 1996) repeatedly shows them to be possible major FC contributors to coastal bays and waterways.

Table 18. Summary of mean monthly bird and seal counts in the Inner Bay with Outer Bay gull and seal counts.

Number of observations ranged from 1 to 4 per month combined from all three types of counts discussed in the text. ND = No Data

	Inner Bay				**Outer Bay**	
Month	**Gulls**	**Ducks & Cormorants**	**Geese**	**Seals**	**Gulls**	**Seals**
Oct	407	416	0	1	500	350
Nov	237	3,453	36	1	225	1
Dec	ND	ND	ND	ND	ND	ND
Jan	300	3,158	249	3	200	0
Feb	182	542	78	2	136	10
Mar	50	ND	ND	0	400	0
Apr	565	737	270	25	443	10
May	508	283	140	1	310	207
Jun	659	134	7	21	482	139
Jul	2,490	40	0	26	1285	130
Aug	984	113	168	67	323	108
Sept	125	50	0	0	1100	0

Duck and geese counts from Outer Bay not included for brevity and due to transient nature of the flocks in that area. Outer Bay gull counts are approximate, mostly restricted to the south shore from the boat launch/oyster company area to the old pier near Three Crabs Beach where gulls and other birds sometimes concentrate.

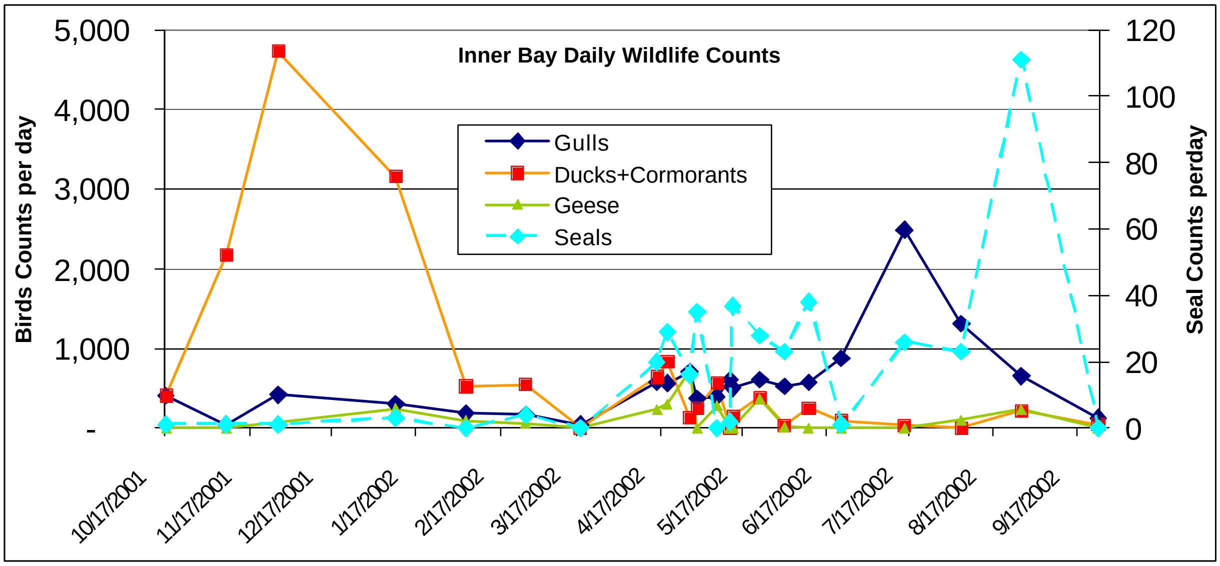

Figure 28. Inner Bay daily wildlife counts, October 2001 - September 2002.

Fecal Matter Consistency: An important consideration in fecal coliform availability in the water column from wildlife involves the nature of the fecal matter, i.e., was it easily soluble or not, and would it be dispersed into the river or bay waters readily or fall to the sea bottom and decay there? On several occasions we endeavored to inspect fecal matter from gulls, geese and ducks. Our observations were made in shallow areas near the River Mouth, on Cline Spit Island and in the water when birds were present in large numbers. With little variation we noted that:

Gulls in Dungeness Bay produced a viscous, liquid-like fecal matter "pellet". In shallow water or at the tide line near the river mouth, a favorite congregating area for gulls, we watched for individual birds to defecate, then immediately inspected the consistency of the fecal matter by disturbing it with our boots, if in the water; or probing it with a stick, if on the shore. In shallow water, the fecal matter would very quickly dissipate into the water column. Above the tide line, no fecal "pellet" was seen, but usually just a very liquid stool. In the literature I could only find information for Great Britain where Gould and Fletcher (1978) studied several species of caged birds that produced varying amounts of liquid versus solid fecal matter. They characterized and sampled ten differing types of wastes, but unfortunately did not report aqueous versus solid proportions. As gulls and other birds produce mixed fecal and excretory (nitrogenous) wastes, the proportions no doubt vary considerably depending on diet.

Geese left more of a true fecal pellet that was consistent and dense, not watery like the gulls. Researchers rely upon this in sampling studies so that birds do not have to be sacrificed, but rather fecal pellets can just be picked up from a pre-cleaned transect (e.g., Converse et al. 1999). We did not perform buoyancy tests, but assume that these pellets would sink fairly fast as they are typically large and dense.

Duck (dabbling, diving and seaduck) fecal matter was not directly examined due to the avoidance of nearshore or beach habitats by these birds. From observations elsewhere (in ponds at my rural acreage) and discussions with hunters, and notations in the literature (e.g., Kuhn et al. 2002) I can conclude that dabbling duck fecal matter is generally quite liquid rather than solid and hence relatively easily-dissolved compared to that of some other taxa such as geese.

Harbor Seal scat was not observed specifically for this study but from prior observations I have made at log rafting facilities in Puget Sound I know that it is generally well-formed, sometimes oily in nature, but nevertheless dense and apparently sinks rapidly. Dissolution will occur, but for the purposes of shellfish safety, the depth of dissolution and the physical nature of the receiving waters are paramount in importance. Water adjacent to seal haul out area most commonly used in Inner Dungeness Bay, the northeast shore of Cline Spit Island, is relatively deep and extremely well flushed, with current velocities regularly exceeding 50 cm/s. The coarse bottom substrate in this area and to the north where seals will haul out at low tides is further evidence of high tidal water velocities.

Collection and evaluation of captive seal fecal matter for hard parts such as fish vertebrae and otoliths is practiced by researchers to gain insight into the degree of prey “hard part” digestion and elimination (Cottrell et al. 1996). Judging from a review of literature titles in this regard, considerable study and debate has centered on how representative fecal sampling is of prey composition. But the physical nature and properties of the scat were not discussed in the few papers I was able to evaluate.

Other studies in Puget Sound have found “high levels” of fecal coliforms in water and shellfish within sheltered environments, e.g., in Still Harbor, an embayment of McNeil Island that has been reported as the largest haul-out area for harbor seals in Puget Sound (Calambokidis et al. 1989). In that study “*fecal coliform concentrations in both water and shellfish were highest at stations closest to the haul-out area. Bacteria also entered the bay from several small seasonal streams entering the harbor. The fecal coliform loading of these streams was far less than that calculated for seals, and the distribution of contamination was not consistent with these streams being the major source of fecal coliforms*”. The physics of water motion in Still Harbor and the seal haul out on the east shore of Cline Spit Island in Dungeness Bay are probably very different, the latter being subjected to very high water transport rates and daily scouring by tidal flushing. Other studies were conducted near the mouth of the Dosewallips River Delta in Hood Canal which is also relatively quiescent and shallow, at least in summer and early fall, compared to Cline Spit Island.

Effective FC Production Rate by Wildlife, Coefficients of Availability: The above information is here converted into an initial estimate of FC availability in the water column from wildlife, by major taxa (Table 19). Only a portion of wildlife FC within their fecal matter enters the water column (e.g., Calambokidis 1989). Not much definitive information is available in the wildlife literature regarding consistency, sinking rates, and solubility of bird or harbor seal fecal matter. Nor is there much information available regarding resuspension and dissolution of wildlife fecal matter in aquatic systems. However, there is a large body of information available for salmon net pens and resuspension of fecal matter after it sinks to the bottom (see recent review by Cromey et al. 2002). From the literature, personal knowledge and the above reviewed information, it is possible to make some first order projections regarding these matters. It is also probable that even well-formed, dense bird fecal pellets that sink to the bottom are easily resuspended in Entry Zone to the Inner Bay and channel areas east and south of Cline Spit Island, thus becoming available to the surface waters and testing for shellfish safety. Further west in the Inner Bay, it is much less likely to have bottom currents sufficient to cause resuspension (~10-20 cm/s, Cromey et al. 2002), hence well-formed, dense fecal pellets from wildlife probably remain on the bottom except during extremely large amplitude tidal events. The gradation of bottom sediments from fine silt and clay in the West Inner Bay to coarse sand and gravel bottoms near the Entry Zone is evidence of this range of tidal water velocity.

Table 19. Initial wildlife FC availability factor estimates for Inner Dungeness Bay.

Availability Factor	Harbor Seals	Ducks & Cormorants	Geese	Gulls
a) Percent rapidly soluble in water column	10%	30%	15%	30%
b) Animal mobility: time in Inner Bay	80%	30%	30%	40%
c) Percent water vs. land “roosting” and feeding	50%	90%	30%	10%
Total (a x b x c)	4.0%	8.1%	1.4%	1.2%

Given the lack of literature information on this topic, I developed some rough estimates of FC availability in the upper water column (i.e., surface water and mid depths) based on my observations and prior experience with wildlife fecal matter in Puget Sound. Note that the values selected here are relatively low, ranging from 1.4 to 8.1% availability. The remainder is not lost immediately, but sinks to the bottom within or on fecal and other settleable solids where bacterial die off may occur. These factors are varied as primary unknown variables in a sensitivity analysis later in this report and are not considered definitive at this point.

While this approach is undeniably somewhat arbitrary, I point out that TMDL studies rarely even address this very important issue (e.g., Virginia Tech 2000) or worse, assume no contribution by wildlife whatsoever (examples not cited but available from the author). Again, I do not assume that these estimates are necessarily correct but vary them in the sensitivity analysis later in this chapter. See also *Recommendations* for further discussion.

Seal Population Facts and Trends: PSWQAT (2002) reports results of Washington Department of Fish and Wildlife trend analysis since 1978 when protection by the Marine Mammal Protection Act began. Harbor seal populations have increased in the region by a factor of three in that time. The greatest increases were recorded in the Strait of Juan de Fuca and in the San Juan Islands. In the Strait of Juan de Fuca the population index has increased from 417 to 1752 individual seal counts in the period 1978 to 1999, accounting for about 9% of the statewide population at the later date. Other recent studies (Jeffries et al. 2003) suggest that the Puget Sound population growth has recently leveled off. No data exist from early the 19th century to estimate historical populations and with changes in prey species populations such comparisons are probably moot. Figure 29 from Huber and Laake (2003, based on Jefferies et al. 2003) shows the temporal trend for the Strait of Juan de Fuca harbor seal population.

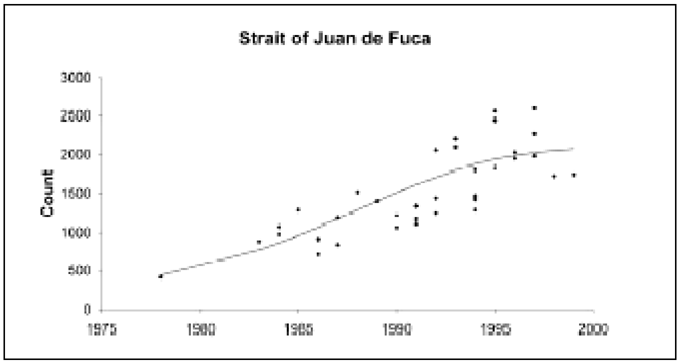

Figure 29. Generalized logistic growth curve fitted to Strait of Juan de Fuca area harbor seal population from Huber and Laake (2003).

Jeffries et al. (2000) is a useful reference detailing the distribution of seal and sea lion haul out sites in Western Washington. For Dungeness Bay, they report counts[5] of 100-500 marine mammals (mostly harbor seals) at the end of the main spit which is in line with my observations in the past few years. They also report similar numbers for the end of Graveyard Spit, but the map indicates Cline Spit Island. In either event, that range would not be appropriate for the past several years based on our experience. The atlas reports an additional <100 marine mammals both for the northeast Inner Bay and the Western Inner Bay which is true at low tide for the former but the Western Inner Bay rarely has any seals present except during salmon runs.

Temporal and Spatial Harbor Seal Distribution in Dungeness Bay: A primary finding of this study was that the Inner Bay is nearly devoid of harbor seals virtually throughout the winter months. Accordingly, their FC contribution at that time is very minimal. Some local fishers and others have told me that seals are frequent users of the bay year round, but this was not the case in my observations and does not agree with the more substantial USFWS refuge staff observations. The seals move out of the Inner Bay during the winter and disperse throughout larger areas of the Strait of Juan de Fuca. Counts at the end of the main spit, which are highly variable depending on tide and weather, were relatively low during winter too. Conversely, seals tend to aggregate upon Cline Spit Island during the late spring and summer for pupping and molting, and indeed I have seen several young of the year and newborns on or near the island.

Harbor seals were most common on Cline Spit Island when present in the Inner Bay. The island is quite small, but is isolated from the mainland and the main spit and as such forms a sanctuary for the seals. The Northeast side of the island is their most favored haul out area, as the beach substrate is sandy and they apparently prefer the protection afforded by the crest of the island from the spring to fall prevailing west wind. Harbor seals may be seen anywhere in the waters of the Inner Bay but my observations suggest they most frequently patrol the passage between Cline Spit Island and Graveyard Spit and several hundred meters northward. They also frequent the entry area south of Graveyard Spit as well as the Main Channel leading out through the Outer Bay.

Regional Bird Population Facts and Trends: The Puget Sound Ambient Monitoring Program (PSAMP) has been systematically surveying wintering nearshore marine birds in Puget Sound and approaches since 1992. Data from Marine Ecosystem Analysis (MESA) studies in 1978-79 are also available for comparison in North Puget Sound and the Strait of Juan de Fuca. These data are summarized in PSWQAT (2002) and suggest significant changes for certain species, some increasing in number, others declining for the Strait and North Puget Sound area. For the groups of particular interest to this study, Black Brandt declined 66% which is generally consistent with local USFWS trend analysis discussed in the phase 1 report. Gulls are thought to have stable to slightly declining populations in the entire region, but for Dungeness Bay there are no useful long term records as the USFWS does not include the south shore of the Outer Bay where we found large numbers to accumulate. It is possible that gull populations have increased in recent years in the Dungeness Bay region, but there is no comprehensive information available. There has been speculation extirpation of gulls from other areas where Bald Eagles, who may prey on and compete with gulls, are recovering such as the San Juan Islands and Hood Canal. But this is not known with regard to

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[5] Counts are probably from annual low tide aerial surveys in August, although not stated in this reference, see other cited references by some of the same authors.

the Dungeness Bay area[6]. Wintering cormorant populations have not changed much since 1992 but are thought to have declined between the 1978 to 1992 period.

Temporal and Spatial Gull Distribution in Dungeness Bay: Many of our observations regarding bird behavior involve gulls. As discussed below, gulls are a year round abundant inhabitant of the Dungeness Bay area. In general, the largest concentrations were seen either in the Cline Spit Island area (including Graveyard Spit, Cline Spit and the shoals in the northern Inner Bay at low tide) as well as the south shore of the Outer Bay with a focus at the river mouth. As we spent many hours per day in the field, we sometimes noted that they would fly en mass back and forth between the Cline Spit Island and River Mouth-South Shore areas. In the spring and summer there were occasional clusters of gulls seen along the south side of the main spit from the far western Inner Bay and also on the shore of the main spit in the Outer Bay. We were unable to determine where or when they did their feeding and in fact noted that they most often did not appear to be actively feeding in any of the above mentioned areas. There are no data regarding annual trends of gull populations in the Dungeness Bay area to the best of my knowledge. Figure 28 shows a significant increase of gull numbers in late summer, and this may be due to migrant gulls known to pass through the area at this time (pers. comm. R. Boekelheide, Dungeness River Audubon Center, 9 April 2003). Apparently the USFWS refuge counts do not include the south shore areas of the outer bay and therefore may not include some of the gulls birds during the spring and summer period.

As part of the Marine Ecosystem Analysis Program (MESA) Manwual et al. (1979) conducted extensive surveys of the calendar seasonal distribution and abundance of marine bird populations in the Strait in 1978. These workers reported a projected (estimated) total abundance of gulls and terns in Inner and Outer Dungeness Bay and Spit areas. I recalculated our year 2001-02 counts to match their seasonal timing and found generally fewer gulls during winter, summer and fall, but more of these birds by a factor of three in the outer bay during spring. The data are not presented here as they are in other ways not exactly comparable, with the 1978 data including both sides of the main spit, for example. Moreover, single year counts may not be indicative of long-term trends of wildlife abundance.

Effect of Birds at River Mouth in Spring and Summer: During the winter, daylight tides are generally quite high in the subject area and some birds congregate at the river mouth. During the spring and summer, however, low tides occur periodically during daylight. It was noted in March 2002 that this afforded an opportunity to measure FC above and below birds, as at lower tides the river flows across the sand flats in a few to several braided streams. We did not have the resources to sample all of the channels, but generally selected one of the middle branches. Prior to and during this sampling, estimates of the types and numbers of birds present were made; separate from the subarea counts performed routinely during all surveys.

The most abundant bird species group present during these tides were gulls. They are attracted to the freshwater river channel and appeared to spend considerable time bathing and loitering about in or near the river mouth. Curiously, we rarely observed feeding activity in this area and the vast majority of the birds were simply standing ankle deep in the river or near the water line, or immediately adjacent to the water line (Fig. 30). Gulls are opportunistic feeders and apparently were feeding to some limited degree on small fish, crustaceans and other organisms in this area. The gulls were not disturbed by our sampling efforts but at times some would fly up or down the beach or across the channel to Graveyard Spit or Cline Spit Island. We inspected their fecal leavings on several occasions and found them to be universally

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[6] Personal Communication, David Nysewander, WDFW and author of the PSWQAT chapter on bird populations trends.

watery, and when deposited in water no well-formed pellet was noticed. A single pass with a boot would easily mix the fecal matter into the water. On one occasion large numbers of Brandt were present and on another, Canada geese were numerically dominant. Ducks were much less abundant during these samplings, although widgeons were present in large numbers immediately after sampling on another day (Appendix E). Typically these birds were very mobile, like most dabbling ducks, and moved quickly in flocks from one area to another.

Figure 30. Left: gulls at the mouth of Dungeness River on August 27, 2002 at a relatively high tide. Right: gulls clustered in shallows from the river mouth eastward toward the old pier in the outer bay.

There were nine separate sampling days for this analysis, with a total of 56 individual samples. Results of the upstream samples were somewhat similar to the River Mile 0.1 samples, but about 20% lower geometric mean overall and not statistically different (as previously discussed). Seven of nine sampling days produced relatively higher downstream than upstream FC geometric means, and two other days had results approximately equal (Fig. 32). On the other two days, there were large numbers of gulls in the general area but few in the river channel immediately prior to sampling. Collectively, the ratio of downstream to upstream geometric mean FC was 4.0 (appendix E). Clearly the birds, especially gulls, were having a major effect on FC loading which was additive to the load already present from upstream, in-river sources.

I examined records of tidal level during sampling and compared it to birds abundance by taxonomic grouping and could find no consistent trend except the prevalence of gulls. Geese did not seem to produce a similar FC effect, but their occurrence was too limited to conduct many measurements. Correlation analysis suggests that tidal height appears to be relatively the most important factor (r = -0.48), not bird abundance in the general area. Tidal height is important because the gulls tend to accumulate at low and moderately low tides in this area during the spring and summer, but at higher tides they often leave the area entirely. Moreover, a lower tidal level acts to force the gulls into a narrower river mouth area while the river provides a conduit of their fecal matter to be delivered downstream and directly into the main channel feeding into the Inner Bay. At higher tides, the river's energy is dissipated into a broader area and tidal currents, which flow perpendicular to the river plume, become the dominant physical factor and the flow rates are typically much less than in the main channel.

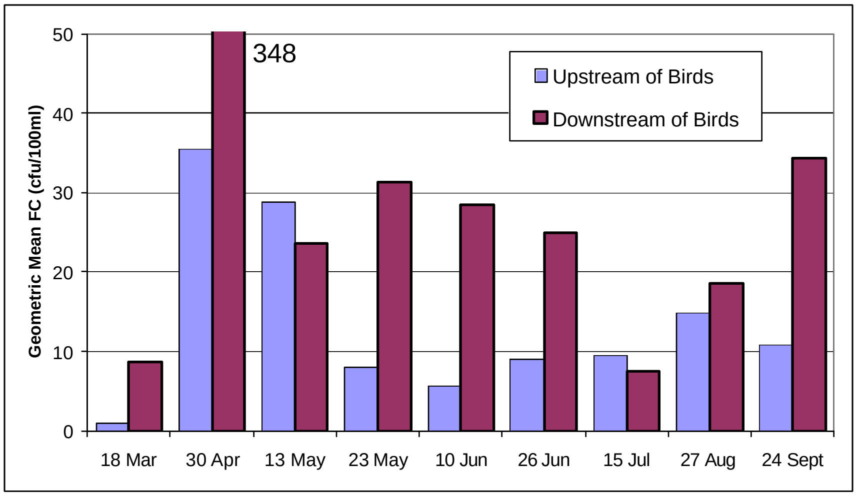

Figure 31. Geometric mean fecal coliform upstream and downstream of birds, mostly gulls present in the river mouth, typically at lower tidal levels, March through September 2002.

If the river was located in, or closer to, the Inner Bay this bird effect would be a highly significant effect upon FC loads in that area. As such, I believe it is much less and of a seasonal nature. During the wintertime, and at moderately high and higher tides at other times, birds at the river mouth will affect FC loads in that area, but it would be impossible to measure.

The effects bird fecal coliform load at the river mouth is accounted for below through the use of these same data to calculate river load. It may be argued that the effect is diurnal, with daytime loading more important in the spring and accordingly I reduced the effect by weighting the seasonal loading with ½ upstream and ½ downstream measured effects. This approximately accounts for a 12 h light – 12 h dark cycle. This is a gross approximation at best, but given the amount and quality of data, it is not possible to develop a more precise estimate. Moreover, these estimates are about the same if all data are used from the river mouth.

With regard to other seasons besides winter, the geometric mean and 90th percentile results for the Inner Bay were much lower than the winter. During these times, large numbers of birds, especially gulls, still inhabited the subject area. However, the numbers of dabbling ducks declined significantly, by approximately an order of magnitude. Many of the birds that remained, such as the gulls, frequented shoreline area above the tide line during the day and also at night for roosting, such as at Cline Spit Island. Dr. Elston and I made observations of this in the spring at night too, using night vision binoculars while in kayaks. Some gulls are always to be found on the water but some of these (many appear to be juveniles) are actually responding to boat traffic and begging for food. Land versus sea location for a bird species is important in developing estimates of where fecal wastes and coliforms are deposited.

Effect of Harbor Seals: As previously noted, seals were essentially not a factor at all during the critical winter season in the Inner Bay. They simply were not present. In both phase 1 and phase 2 of this study we collected fecal coliform samples up and downstream of the harbor seal haul out area on the east side of Cline Spit Island. Samples were collected very near shore, from the surface and subsurface in depths of ½ m or less and often resulted in high fecal coliform results for surface samples. Deeper water and offshore samples in the same area rarely yielded any result above ambient concentrations. Clearly harbor seals contribute to the FC load of Inner Dungeness Bay, but because of the density and consistency of their fecal matter, and the limited spatial effect we found in the field, I do not believe their effect is significant compared to other sources. It is interesting to note that during the late summer of 2002 Tribal gillnet fishers were actively discouraging seals from the Cline Spit area although they had been there the previous sampling period. At that time we collected additional up and downstream samples around the haul out area and found no increase above background FC results.

Correlation of FC and Wildlife Abundance in Inner Bay: Before applying FC production rates to observed wildlife abundances to estimate loads, it is useful to examine daily wildlife abundance estimates of discrete subareas in comparison to observed FC results. I didn't expect strong correlations in dynamic areas such as the Entry Zone to the Inner Bay (area 3.1) which flushes very fast. Alternatively, Inner Bay areas such as the Convergence Zone and the West Inner Bay flush much more slowly and might retain a possible FC signal of wildlife origin. As shown in Table 20, combined ducks and cormorants abundance was positively correlated with FC concentrations over the entire year (r = 0.81 to 0.84). Conversely, abundance of gulls, geese and harbor seals compared to FC values produced weakly negative correlations. Given the large numbers of ducks in the winter and the nature of duck fecal matter, previously discussed, as well as their behavior patterns (i.e., remaining in the water all day), the dabbling ducks were prime candidates for having a major seasonal effect. But a correlation is not proof of cause, so the other likely candidate source, the river, had to be examined in more detail.

Table 20. Correlation matrix between annual geometric mean fecal coliform and selected wildlife taxa abundance for two Inner Dungeness Bay subareas.

Subarea	Subarea Code	Ducks (& Cormorants)	Geese	Gulls	Seals
West Inner bay	4.1	**0.81**	-0.02	-0.23	-0.37
Convergence Zone	3.2	**0.86**	-0.02	-0.12	-0.26

Fecal coliform production rates: FC production rates vary among species and are summarized in Table 21. These data should be viewed as first order estimates, i.e., there may be large variation from one animal to the next, and variation with season, diet, body size, etc.

Therefore, applying averages to the above production rates (organisms/day) yields the following:

seals 1.52×10^9,
ducks 1.7×10^9,
geese 0.04×10^9,
gulls 1.7×10^9

Table 21. Fecal coliform estimates in animal feces and comparison to humans.

Animal	Fecal Coliform *Org/g*	Ref.	Feces Production *g/d*	Ref.	Fecal Coliform Production *10^9Org/d*	Ref.
Duck (spp?)	33,000,000	A	-		2.4 or 1.0	D, E
Goose (spp?)	-		-		0.79 or 0.01	D, E
Gulls (many spp.)	-		-		1.64 or 1.7	F, G
Harbor Seal	31,000,000	B	375	B	11.6	B
Harbor Seal	53,800,000	C	350	C	18.8	C
Human	13,000,000	A	150	A	2.0	A

References:	A	Geldreich (1966 or 1978)
	B	Welch and Banks (1987)
	C	Calambokidis et al. (1989)
	D	ASAE 1998 as interpreted by Virginia Tech (2000) apparently for average 3 lb. ducks
	E	References cited in Weiskel et al. 1969
	F	Gould and Fletcher 1978, my calculated mean of their Table 2.
	G	NYCDEP (1993), note interesting agreement with F above

These above population, availability and daily production rate data are combined to produce Table 22.

Table 22. Seasonal wildlife FC loading estimates (cfu/day) and annually (cfu/yr) for Inner Dungeness Bay.

Population mean x Production rate from literature x availability factor = loading to water column

Time Period	Parameter	Harbor Seals	Ducks & Cormorants	Geese	Gulls
November-February	**Mean Population->**	2	2384	121	239
	Per season	1.5.E+11	3.9E+13	7.9E+10	5.9E+11
	Per day	1.2.E+09	3.3E+11	6.6E+08	4.9E+09
March-July	**Mean Population->**	18	298	104	1055
	Per season	1.0 E+12	6.3E+12	8.7E+10	3.3E+12
	Per day	6.9 E+09	4.1E+10	5.7E+08	2.2E+10
August-October	**Mean Population->**	23	193	56	505
	Per season	7.9 E+11	2.4E+12	2.8E+10	9.5E+11
	Per day	8.6E+09	2.7E+10	3.1E+08	1.0E+10
Annual loading	Total cfu/yr	3.1 E+12	4.8E+13	2.0E+11	4.8E+12
% of Wildlife Annually	by Taxa	2.9%	90.7%	0.2%	6.1%

mean population refers to the mean seasonal abundance of the particular type of wildlife

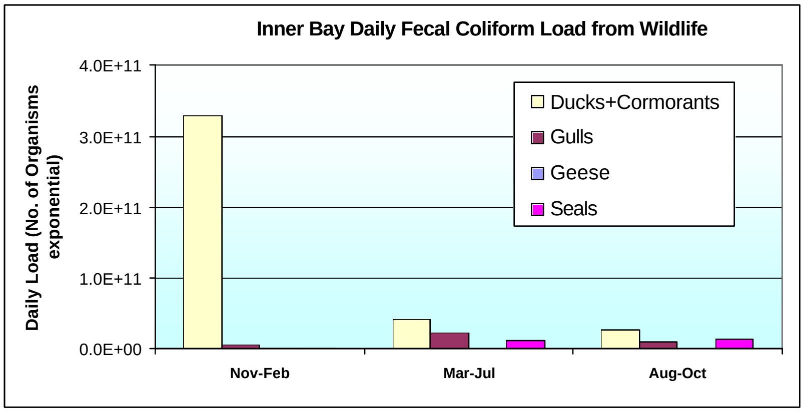

Figure 32. Seasonal Inner Bay estimated daily fecal coliform loading from four taxa of wildlife.

In summary, the fecal coliform production and availability rates for wildlife in the Inner Bay has been calculated to total about 6.6 x 10^{13} FC per year suggesting that they are the primary FC source within the Inner Bay. Much of this loading occurs in the critical winter season and probably can be attributed to ducks and cormorants. These results should be viewed and interpreted with caution because of the stated assumptions. The availability rates are varied in Section 7.14 as a sensitivity analysis of the mass balance accounting.

7.9 Comparison of River and Bird Sources

As both Dungeness River sources and wild birds appear to be major sources of FC loading to Dungeness Bay, some further efforts to estimate their relative importance are explored here. Table 23 presents a correlation matrix to examines possible associations, in particular FC loading (FC mean concentrations x mean of prior 2 days+ sampling day flow) from the river.

Table 23. Correlation matrix for factors influencing Inner Bay Convergence Zone (above) and River Mouth (below) areas.

Inner Bay: Area 3.2 Convergence Zone	**River Discharge**	**River FC Load**	**Surface Salinity**	**Duck Abundance**	**Gull Abundance**	**Geometric Mean FC**
River Discharge*	1.0	0.31	-0.61	**0.64**	-0.08	**0.65**
River FC Load		1.0	0.03	0.12	-0.28	-0.05
Surface Salinity			1.0	**-0.77**	0.26	**-0.62**
Duck Abundance**				1.0	-0.28	**0.86**
Gulls Abundance					1.0	-0.23
Geometric Mean FC						1.0

Area 2: River Mouth	**River Discharge**	**River FC Load**	**Surface Salinity**	**Gulls Abundance**	**Geometric Mean FC**
River Discharge*	1.0	0.31	0.01	-0.13	-0.06
River FC Load		1.0	-0.12	-0.25	**0.91**
Surface Salinity			1.0	-0.42	-0.26
Gulls Abundance				1.0	-0.14
Geometric Mean FC					1.0

* river discharge average over prior two days and sampling day. Same data applied to River load.
** Ducks counts include cormorants.

The results indicate no positive correlation of river FC load and geometric mean FC in area 3.2 of the Inner Bay. This area was the most likely to reveal an association, due to relatively slow flushing rates previously discussed. Similar results for all factors were seen for the West Inner Bay. River discharge and surface salinity x FC geometric mean had moderately high correlation coefficients, but were less than that of duck abundance x FC geometric mean.

Conversely, the River Mouth area had a strong positive correlation between river FC load and geometric mean FC with a correlation coefficient of 0.91. That was the only moderate to strong correlation. Salinity should have been inversely correlated with river discharge or geometric mean FC, but the lack of variation in calm weather with salinity = 0 psu and mixing in the winter and stormy weather obfuscated these relationships.

Gull abundance is important to river mouth FC loading, as the prior upstream to downstream analysis showed, but gull abundance in this correlation matrix refers to total abundance in the entire river mouth area that includes about 2 km of beach. Gulls were distributed non-normally in various locations throughout the south shore of the river mouth area, not just in the river channel itself.

The strong correlation of river FC load to FC geometric mean results at the river mouth (r = 0.91) remains in stark contrast to that of the Inner Bay (r = -0.05)[7]. Collectively, these data and our general knowledge of circulation and mixing in the bay suggest that the river is the primary and dominating influence on FC bacterial conditions near the river mouth but the Inner Bay is likely a mixture of river and bird effects. The evidence suggests that birds are primarily responsible for FC loading in the Inner Bay. The study year was a worst-case analysis for river effects, i.e., in an average river discharge year the effects would likely be less.

As one final measure to examine these two primary factors, I statistically compared the correlation coefficients for the Inner Bay (Convergence Zone) from the above table using a procedure outlined by Zar (1996) that involves the Fisher *z* transformation. The null hypothesis is no difference between correlation coefficients, and the alternative is the opposite. The results indicated a significant difference ($P<0.05$) between correlation coefficients for duck abundance versus river FC load, which was expected given the large observed differences. Moreover, increasing the sample size very slightly resulted in a significant difference. Another comparison between the same duck abundance coefficient and river discharge was not significant. Again, the more important measure for the river should have been river loading, not river volumetric discharge and the former had no positive correlation with FC concentrations in the Inner Bay. Nevertheless, river discharge does appear to have some influence and can not be discounted entirely, particularly during some periods of the winter with strong east winds that result in river plume forcing into the Inner Bay.

Response to Criticisms of Wildlife FC Loading Findings: In preparation of this report and discussions with others, one theme recurs regarding wildlife effects. This is often stated "How can birds be responsible for recent (since 1997) increased FC concentrations in the bay if their populations have been declining?" Such a statement is an oversimplification. The following points should be considered:

- Dabbling and diving ducks and shorebirds over-winter in the Wildlife Refuge vicinity, with over 10,000 individuals sometimes occurring in the area. Dabbling ducks in particular appeared to have declining numbers from a peak in the early 1980s. Mid

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[7] Correlation analysis is strongly affected by outlier, but this was more likely to affect FC counts, not wildlife abundance counts.

winter dabbling duck counts have actually increased annually since 1998, a low point in the counts, in a monotonic fashion (except for the high counts of year 2000).

- Much of the bird data far predates the FC data (i.e., dabbling duck data from 1975). The most useful DOH FC data are from 1991 onward so the two data sets do not overlap well.
- Other large bodied birds include Black Brandt, and their "use days" were more or less stable during the 1990s (see Phase 1 report, Fig. 11), and were not declining in abundance.
- The DOH data was collected infrequently, not monthly through the critical winter season and is not well suited to fine scale correlation work as discussed in the phase 1 report. In other words, I do not believe it is highly useful for trends analysis.
- None of the DOH data are from subsurface depths, which may be more indicative of bird effects in the Inner Bay. If so, no correlation would be expected.
- The DOH data collection stations in the Inner Bay are not suited to detect FC effects by dabbling ducks. With the possible exception of station 108, there are no mid-bay stations that dominated my sampling strategy. Dabbling and diving ducks are found all over the Inner Bay but 7 of 8 DOH stations are relatively near shore and not necessarily where these birds congregate (which tends to be further offshore in both the Inner and Outer Bay given the relatively shallow depths).

Thus it is probably incorrect to assume that FC concentrations throughout the bay have been increasing while bird use, at least large-body ducks and geese, has been declining. Two other points relate to the river:

- The river is an extremely important source of FC affecting marine waters at and near the river mouth. There should be no *a priori* assumption that only one source must impact the entire bay.
- A simple accounting of mean daily river volume versus area of the Inner Bay shows that the river accounts for less than a centimeter of depth over the mean tide surface area of the bay[8]. To be the primary contributing FC source the river would have to have extremely high concentrations of FC, which it does not.

The Phase 1 report identified the river as a probable major contributor to FC loading in Dungeness Bay, i.e., the entire bay, and that has not changed. However, that correlation analysis in that report involved River Mouth and nearby south Entry Zone stations, not Inner Bay stations. There may be additional data concerning wildlife populations in the area, including additional annual trend information and seasonal population fluctuations, as discussed in the *Recommendations*.

The results of the present study suggest the prior, preliminary study that was conducted in spring and summer was not able to consider critical winter season data. Wildlife contribute significant FC loading at certain times and places. This conclusion is reached despite using very conservative assumptions regarding wildlife fecal availability to the water column. Strong correlations between duck abundance and FC concentrations were observed in the Inner Bay, while at the same time riverine contribution is discounted due to simple dilution by marine water as well as lack of correlation with river FC loading rates. I<u>t is strongly emphasized that wildlife are not the only significant source of FC in the bay and that the riverine loading is very important at most times near the river mouth and occasionally in the Inner Bay during peak</u>

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[8] Area of Inner bay at mean tidal height = 4.66 km^2. Mean discharge of river in study year = 18,4 m^3/s, much higher than average. Depth of one tidal cycle's flood tide contribution of river water spread over the entire bay = 8.8 mm.

river loading. Therefore additional measures proposed in the Dungeness River TMDL report to abate fecal coliform loading in the Dungeness River are warranted.

7.10 Failing Septic Systems

For the purposes of this report, septic system failure is an important source of FC pollution to the shellfish closure area that could contribute to increased FC levels in irrigation districts and the river. Based upon an understanding of vicinity soils and water tables, however, failing onsite septic treatment and disposal systems should be fairly uncommon near the Inner Bay. They should be comparatively more common at some locations that are tributary to the Dungeness River. Those that are failing along the Dungeness River and its irrigation ditch tributaries have already been accounted for as a part of the Dungeness River FC load. No additional septic system loading is included in this model. Overall, septic system failure is a serious factor because of the mosaic of irrigation ditches that drain to the Dungeness River and Bay providing a hydraulic conduit, and because human septic waste is potentially highly pathogenic.

7.11 Bacterial Consumption by Filter Feeders

Filter feeding organisms sweep the water clear of food matter, including FC bacteria in some instances. Shellfish, zooplankton and other filter feeding organisms remove particulate matter from seawater. Grazing by suspension-feeding bivalves, which are capable of filtering large volumes of water per unit time, has been shown to play an important role in controlling phytoplankton biomass in shallow estuaries (e.g. Cloern 1982, Officer et al. 1982). A distinction is made between filtering rates, which address the volume of water pumped by an organism per unit time and is not relevant to this investigation, versus clearing rate, which addresses the volume of water swept clear of particles per unit time. Clearing rates by oysters are on the order of 5 L/hr and zooplankton filter at rates of 1 to 6 ml/hr (Frost 1986) when active. To take advantage of the water quality benefits exerted by large populations of filter-feeders, oyster-stocking programs have been carried out in the Chesapeake Bay (e.g. Newell et al 1999). The Chesapeake Bay stocking program was carried out in an attempt to reduce algal concentrations in the water.

However, for the purposes of this report the bacterial die-off rate is considered to include the loss of FC by filter feeders. Further, we do not endorse the stocking of oysters in the closure area as a means of water quality enhancement without the simultaneous performance of other pollution control activities.

7.12 Boaters

In prior decades, live-aboard and recreational boats have been associated with FC contamination (Seabloom 1992), although marine sanitation devices and holding tanks are widely used at present. Inner Dungeness Bay does not receive much or any usage from overnight boaters due to shallow depths, relatively dangerous conditions and the proximity of much better moorage nearby at John Wayne Marina. The Outer Bay does have an occasional yacht or tugboat anchoring. No overnight mooring boats were seen in the Inner Bay during either phase of this study, and public toilet facilities are available for day-use boaters at the Cline Spit and Oyster Company boat ramps. For the purposes of this report, boaters are assumed to contribute no FC directly into the Inner Bay.

7.13 Bacterial Die-Off

Fecal coliform bacteria survive well in the guts of warm-blooded creatures but die-off is relatively rapid in marine waters. The rate of bacterial die-off is routinely calculated with a first order decay equation:

Equation 13. $N_t = N_0\, e^{-kT}$

Where N_t is the number of bacteria at time T, N_0 is the original number to start with, e is the natural logarithm and k is the die-off rate. The die-off rate has been found to be somewhat variable, with a reported range of over 2 orders of magnitude from 0.04/day to over 4.0/day (Bowie et al 1985, Horner et al 1989) or higher depending on the source. The die-off rate increases with exposure to higher levels of salinity, temperature and sunlight (see Gameson and Saxon 1967, Klock 1971, Mancini 1978, Bowie et al 1985, Curtis et al 1992, Aurer and Niehaus 1993). In particular, temperature and light are primary degrading factors (EPA 2001). The general equations for these factors are:

Equation 14 for Temperature: $k_T = k_{20} \times 1.07^{(t-20)}$

Equation 15 for Salinity: $k_S = 0.8 + 0.006\ (\%\ \text{sea water})$

Equation 16 for Light: $k_L = (I_A)(1/E)(1/Z)[1 - e^{(-EZ)}]$

Where, k_T, k_S, and k_L the corrected die-off rates, k_{20} is the die off rate at 20 degrees C, I_A is the average daily solar radiation, E is the light extinction coefficient and Z is the water mixing depth. However, for the purposes of our calculation using a one-year time step, we shall select a single value of k that takes into account the influence of temperature, salinity and light.

As previously shown, the annual range of water temperature in Outer and most of Inner Dungeness Bay is relatively small. Seasonal mean values only varied by about 2°C. Light levels varied much more significantly, but I do not have any site specific information in that regard (i.e., subsurface light measurements). Marine water salinity of the Strait of Juan de Fuca varies less than 10% over the annual cycle, so for the purposes of assigning a first-order estimate of bacterial die off for Dungeness Bay I consider light an important consideration.

During the phase 1 study FC concentrations along drogue pathways were measured in order to make preliminary assessment of die-off rates in Dungeness Bay. Based on 33 paired samples, with a first sample collected wrist deep beside a drogue and then about one-half hour later a second sample collected from beside that same drogue, and solving for k using the equation:

Equation 17 $k = -[\ln(N_t/N_0)](1/t)$

This yielded a calculated decay coefficient, k, of 0.37 per day. However, these measurements were conducted in the late spring and summer when the important factor or light was much more pronounced than in the winter. The conclusion in the Phase 1 study was that the seasonal average die off rate should have been about 0.2 per day. Pelletier and Seiders (2000) found a best-fit annual die off rate of 0.4/day for the Grays Harbor TMDL modeling study. As a related issue they concluded that FC contribution to the (upper) water column by wildlife was much lower than literature values would suggest. However, that project did not include actual wildlife abundance estimates. I expected similar bacterial die-off rates in Dungeness Bay to those seen in Grays Harbor, possibly slightly less.

Given the experimental results and the consideration of seasonal light variation, I choose to assign an annual die off rate for FC bacteria in Dungeness Bay of 0.3 per day which represents an average of best available information. This value is well within the range reported in the literature, and is considered to be a conservative value. Based on this die-off rate, the following equation uses the die off rate (0.3) and water residence time of 0.89 days (21.4 hours) as follows:

Equation 18 $N_t = N_0 e^{-kT} = N_0 e^{-(0.3)(0.89)}$

To solve for the mass balance analysis in the next section, let N_0 represent tidal water flowing into the bay and N_t represent Tidal flow leaving the bay. Die off is applied equally to all sources of FC to the Inner Bay summarized in the next section. I varied the die off rate by several tenths experimentally, and did not find it had a major affect on the overall outcome. By that I mean it only affected the net imbalance between inflow and outflow total load by a few percentage points for the better estimates.

7.14 Summary: Inner Bay Fecal Coliform Sources and Sinks

I have constructed a general framework for assessing sources and sinks of fecal coliform to Inner Dungeness Bay. The analysis is a hybrid of observed and estimated factors, and there are several major revisions compared to the Phase 1 attempt. As in the prior model, this analysis is constructed using data of variable quality but overall is a major improvement over the prior product. Key issues that were speculative in the Phase 1 model were addressed and uncertainty reduced for deeper water FC concentrations and wildlife production rates. This section provides a sensitivity analysis of the less reliable data, i.e., production of FC by wildlife. A summary of loading under three differing scenarios is presented in Table 24. I do not alter the Dungeness River FC concentration, irrigation ditch loads or the input and output loads at the Entry Zone to the Inner Bay as these are all derived from relatively accurate measurements.

Under all conditions of the Table 24, I find that marine water, which includes reflux of Inner Bay water and Dungeness River water, a primary contributor to Inner Bay FC loading. It is important to note that “marine water” is not a source in and of itself, but rather a composite of other sources in both Inner and Outer Bay. It is not possible to separate out the components of this component, but it is safe to assume that FC loads from the river and irrigation ditches are involved, as well as wildlife sources. As the river and ditch sources are controlled and reduced, the contribution of marine water will be diminished significantly.

In all cases Inner Dungeness Bay wildlife, principally birds, are the second largest contributor. The Dungeness River during flood tides is third largest contributor to the Inner Bay but was previously shown to be the dominant source at the river mouth and adjacent marine areas. Irrigation ditches were fourth, and harbor seals were the least important. I stress again that harbor seals are a very significant source immediately adjacent to Cline Spit Island when they are present, but since there were just one or two seals present at any time in the entire Inner Bay during the critical winter season they can not be an important source at that time.

Table 24. Sensitivity analysis of annual fecal coliform bacteria loads to the Inner Dungeness Bay with three differing scenarios.

Number 1 scenario is the one previously discussed in this report using available information and best professional judgment.

		Wildlife FC Availability Estimates		
Inflow to the Inner Bay	**Components**	**1) Initial**	**2) 40% more**	**3) 40% Less**
		(10^9 organisms per year)		
Marine Water	Inner Bay reflux, Outer Bay wildlife & Strait of Juan de Fuca	157,700	157,700	157,700
Wild Birds	Inner Bay only	53,100	74,400	31,900
Dungeness River	0.45 x flood tIde	34,900	34,900	34,900
Irrigation Ditches	Inner Bay	3,500	3,500	3,500
Harbor Seals	Inner Bay only	3,100	4,300	1,900
Total Inflow	Sum of the above five	**252,300**	**274,800**	**229,900**
Loss from Inner Bay				
Tidal Outflow	Measured outflow	230,700	230,700	230,700
Bacterial Die Off	See prior chapter section	64,100	66,600	61,700
Total Losses	Sum of the above two	**294,800**	**297,300**	**292,400**
Net Difference	Outflow minus inflow	**42,500**	**22,500**	**62,500**
Difference as percent		14.4%	7.6%	21.4%

The best fit in terms of minimizing FC differences between input and output to the bay would be to increase the wildlife contribution by about 40% as shown in scenario 2. However, it was previously shown that a there was a net outflow from the Inner Bay, particularly during the winter season. Coincidentally or not, scenario 2 also most closely satisfies the observed 8% annual net outflow of fecal coliform from the Inner Bay. The previously selected wildlife availability factors may be too conservative, or there may be unknown bias or errors in the input and output loading estimates. Nevertheless, manipulation of the wildlife contribution by a very large value of 40% in either direction does not change the rank order of contribution, i.e., marine water, wildlife, river then irrigation ditches. The sensitivity analysis therefore generally validates the prior loading rate estimates to the extent that the relative degrees of impacts among sources are correct.

Seasonal rankings of contribution to the Inner Bay are shown in Figures 34 and 35 for Scenarios 1 and 2, the two most likely outcomes. With the information at hand it is not possible to pinpoint the preferred scenario, but again neither affects the rank order of importance among all sources.

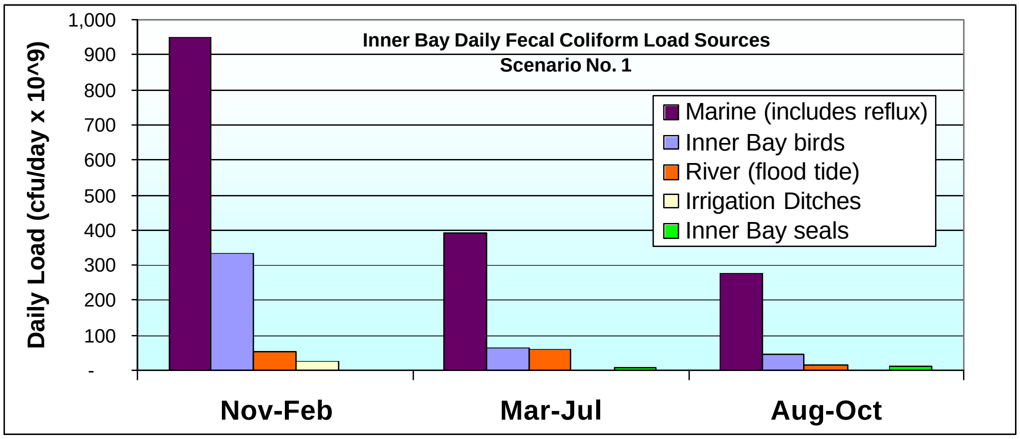

Figure 33. Comparison of Inner Bay FC loading rates by individual sources for the study year, scenario 1, initial analysis.

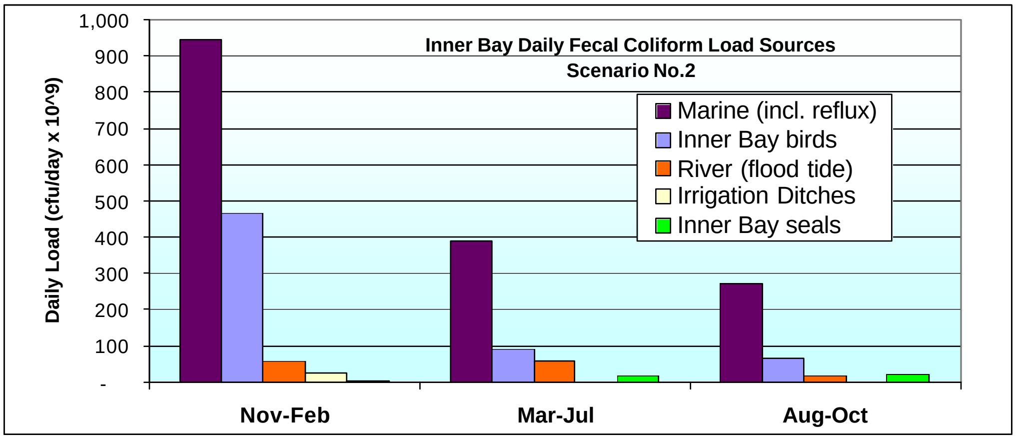

Figure 34. Comparison of Inner Bay FC loading rates by individual sources for the study year, scenario 2, 40% more wildlife contribution.

The reader is reminded once again, these estimates do not apply to the river mouth and adjacent marine areas where in-river sources alone result in violations of water quality standards for fecal coliform. See *Recommendations* for additional means to understand and more accurately account for sources and sinks of fecal coliform in Dungeness Bay.

8 CONCLUSIONS

A year long survey of Dungeness Bay was conducted from October 2001 to September 2002 to examine remaining bathymetry, circulation and fecal coliform issues. Seventeen routine sampling events and several circulation/reflux surveys were mounted. Results are summarized by study topic category:

8.1 Bathymetry and Reflux

Bathymetric maps of Inner Dungeness Bay were revised in this (phase 2) portion of the study. The map was required for tidal volume estimates and to facilitate flushing rate calculations. Additionally, historical US government (NOS) sounding data from 1967 were used to prepare a companion map and volume estimate. From comparison of these two maps, it was found with reasonable certainty that the Inner Bay had about 35% less volume in year 2000 for depths below mean lower low tide (zero foot or meter datum) compared to 1967. There were indications that the volume of depths above mean lower low water had increased slightly, but the older US government data was insufficient to be sure of this possible change. Areas where the bay has changed are discussed.

Drift object (drogue) surveys were conducted to measure the amount of ebb tide water leaving the Inner Bay that returns on the following flood tide (i.e., “reflux”). Reflux rate was experimentally measured to be 45%, much higher than many other bays in Puget Sound, but not surprisingly high given the large area of Outer Dungeness Bay. A persistent reversal of flow during flood tide was noted on several occasions in the northern Outer Bay near the Lighthouse. This could be part of an Outer Bay gyre.

8.2 Fecal Coliform Survey

In general, patterns of fecal coliform occurrence were similar to those found in the Phase 1 study and review of Department of Health historical database. The Phase 2 study, however, included year round and subsurface sampling. Late fall and winter was shown once again to be the critical period for fecal coliform water quality violations for all marine areas, while the river mouth had higher concentrations but lower loads during the spring and summer. The Washington State Class AA marine fecal coliform standards for this area are a geometric mean of 14 organisms per 100 ml and a 90th percentile of 43.

Fecal coliform bacterial levels exceeded water quality criteria regularly at the mouth of the Dungeness River in winter but also during late spring through fall. By comparison of river mouth and in-river stations at river mile 0.1, it appeared that winter violations were due solely to in-river fecal coliform sources. River mouth sampling in spring and summer indicated the same as well as significant contribution by wild birds. Most of the birds were gulls and were attracted to the river mouth for extended periods, apparently for roosting and bathing in the freshwater. The study year results indicate that the achievement of a 13 organism per 100 ml geometric mean would be protective of the river mouth area, except during times when there is high bird abundance directly in the river plume. The river has some modest effect on FC concentrations in the Inner Bay during winter, but during spring and summer its effects are minimal, probably due to environmental factors associated with bacterial die off.

Source waters of the Strait of Juan de Fuca were very low in FC bacteria content and Outer (eastern) Bay waters were only slightly elevated in comparison. Vertical stratification of fecal coliform concentrations was not apparent in these areas.

Irrigation ditches flowing into the Inner Bay had variable and generally very high fecal coliform concentrations that occurred periodically but year round when flow was present.

Inner Bay areas showed similar geometric mean FC patterns, with peak concentrations of combined surface and subsurface results nominally exceeding water quality standards in winter but relatively low concentrations at other times. The most interesting and surprising result of this survey was the discovery of persistent, relatively high concentration subsurface fecal coliform reservoir in winter in the Inner Bay. This feature was not seen in the Outer Bay and can not be explained at present but may involve settling of fecal coliform from birds combined with reduced die off as a result of low light exposure.

Sediment sampling during April 2002 in non-littoral areas showed that sediments were not a likely reservoir of fecal coliform bacteria. Prior near shore sampling in the Phase 1 study indicated the same, with the exception of a few specific locations including the harbor seal haul out beach on Cline Spit Island.

The obvious conclusion one could draw from this portion of the study is that except for winter, Inner Dungeness Bay has fairly acceptable FC conditions. This conclusion does not exactly match that of the Department of Health (DOH) monitoring program for shellfish harvesting, but there are a number of reasons advanced to explain the difference between the data sets. First it should be noted that the present sampling program was not designed to test the accuracy of the DOH program. Station selection by DOH is very nearshore in most cases versus my stations which were purposely offshore to measure the vast bulk of water moving through channels and subareas. The DOH sampling program uses a different type of fecal coliform measurement (MPN) that sometimes yields higher results than the methods used by the contract laboratory (MF). DOH samples primarily at higher tidal levels, usually on a flood tide. This may result in sampling the Inner Bay just as a fresh load of river source FC has entered. Sampling at high tide also allows the sampling boat to move near the three south shore Inner Bay sampling stations of DOH, where highly polluted irrigation ditch flow spreads out over the surface of the seawater as mentioned above. My sampling was conducted at a variety of differing tidal phases. As noted in the Phase 1 study, the limited frequency of sampling of the DOH program should mean that great caution be used in application of the data for trend and time series analysis. In other words, we can't be entirely sure about apparent interannual observed FC differences when sampling is only conducted over the range of once a month to once per quarter basis. Other considerations in this comparison are discussed herein.

8.3 Fecal Coliform Loading

Fecal coliform loading estimates were prepared for the Inner Bay. No attempt was made to model the Outer Bay or river mouth area as circulation and flushing is much more complex in these areas. By order of importance fecal coliform sources to the Inner Bay are:

1. "Marine" water that includes Strait of Juan de Fuca water, reflux of Inner Bay and Dungeness River waters and part of the Outer Bay wildlife inputs,
2. Inner Bay wild birds especially ducks,
3. Dungeness River discharge including gull contributions in the river plume,
4. Irrigation ditches that flow year round, and
5. Inner Bay seals

Marine water flowing into the Inner Bay was by far the greatest water volume, so despite its relatively low seasonal FC geometric mean concentrations (1.4 to 4.8 colonies/100ml) it dwarfed all other loading sources. A significant proportion of this load is Inner Bay reflux water, or water previously in the Inner Bay that was swept out with the ebb tide and returned on subsequent flood tides. It is important to note that "marine water" is not a source in and of itself, but rather a composite of other sources in both Inner and Outer Bay. It is not possible to separate out the components of this component, but it is safe to assume that FC loads from the river and irrigation ditches are involved, as well as wildlife sources. As the river and ditch sources are controlled and reduced, the contribution of marine water will be diminished significantly. Wildlife in the Inner Bay account for a large, but undetermined percentage of the outbound FC load, so in fact marine water inflow is also a measure of their impact. Wildlife in the Outer Bay also contributed to the marine water load, but their contribution is less for reasons involving hydraulic circulation. Many Outer Bay birds, especially the gulls, tend to concentrate along the south shore where tidal transport on the ebb tide removes a relatively large volume of the water into the persistent southeasterly flow past Three Crabs Beach and towards Jamestown. It is not possible or necessary to discern the exact contribution rate of the Outer Bay sources at this point, as the modeling focuses on the Inner Bay. However, the manner in which I conducted the study did account separately for the birds immediately in the river mouth which was important as the river plume transports some of their fecal coliform directly to the Inner Bay during flood tide.

Inner Bay wild birds are the second most important source of fecal coliform bacteria to the Inner Bay on a year-round basis. They are especially importantly in the winter, when their load approaches ½ of the measured marine water input. In the spring the bird's contribution shrinks with their population to about the same load rate as the flood tide river component. Wildlife fecal coliform production was estimated by applying population counts to known FC production rates and further reducing loads by availability coefficients to account for sinking of wastes, animal mobility and relative dissolution rates. Strong positive correlations were seen between wild bird population counts and observed FC measurements in the Inner Bay. The importance of wild birds was further verified through correlation analysis and comparison of correlation coefficients to other loading sources, including the river. In particular, duck abundance was highly correlated with fecal coliform concentrations. The nature, consistency and solubility of their fecal matter is such that this would be expected, compared to other large-bodied birds frequenting the area.

Dungeness River: As mentioned above, direct and indirect evidence indicates that the in-river sources of fecal coliform to the Dungeness River are a primary cause of frequent water quality violations at the river mouth and immediately adjacent marine water stations. In spring and summer the situation is exacerbated by congregations of gulls and other birds directly in the river mouth and adjacent areas. At low to moderate tides the river flows across the sand flats entraining the gull fecal wastes and increasing measured concentrations of FC by several times. Periodic measurements upstream and downstream of the gulls showed a significant impact of these birds on fecal coliform loading. But their impact is not continuous, for bird presence varies considerably by tide and time of day. Moreover, fecal matter from birds NOT located in the river plume are subject only to along shore movement by tidal forces and are likely to die off from enhanced light penetration in the clearer marine waters of these shallow areas. This area is also relatively well flushed out of the bay, as discussed above. These factors were accounted for in the data analysis by including data from all seasons, tides and wildlife presence conditions. Empirical observations here must be relied upon rather than modeling.

Irrigation ditch returns were significant contributors to fecal coliform load during the winter, contributing more than 96% of their annual fecal coliform load at that time. During other seasons they may be responsible for periodic high fecal coliform testing results due to the location of sampling stations of the Department of Health. As previously noted, the total fecal coliform load from these ditches is low compared to other sources, but they are important in terms of shellfish safety and bay certification. During relatively calm days in the winter their effects could affect a large area of the Inner Bay as the density of this source is much less than seawater and will spread over the surface in a relatively thin film. Efforts should continue to identify and control fecal coliform sources to the ditches.

Harbor seals are almost entirely absent from the Inner Bay during the critical winter season; hence they are not responsible for fecal coliform loading at that time. Their numbers increase in spring and summer in the Inner Bay, but their impacts on bacterial loading appears to be localized near the primary seal haul out on Cline Spit Island. Adjusting for the fast flushing rates in this area, these findings are consistent with studies of seal FC impacts from Puget Sound.

8.4 Summary of Water Quality Standard Compliance or Violation

The following summarizes findings with respect to the stated water quality standards. The WAC standards are not specific with regard to the time period to be considered, so both daily and seasonal geometric mean results are considered. Only seasonal 90th percentile results are considered as daily results are inadequate to produce a meaningful distribution.

*Areas and timings that exceed **geometric mean** fecal coliform standards on **seasonal** basis:*

Dungeness River mile 0.1: Nov-Feb and Aug-Oct
Dungeness River mouth: Mar-Jul and Aug-Oct

*Areas and timings that exceed **90th Percentile** fecal coliform standards on **seasonal** basis:*

West Inner Bay and Cline Spit Gyre: Nov-Feb
Dungeness River mile 0.1 March-July and Aug-Oct
(River mouth was close to exceeding in same period)

*Areas meeting **both standards on seasonal** basis:*

Strait of Juan de Fuca near Dungeness Spit.
Outer Dungeness Bay (as defined herein)
Entry Zone (north and south)
Convergence Zone
N.E. Inner Bay

9 RECOMMENDATIONS

Some remaining issues could be clarified to provide further understanding of the dynamics of Dungeness Bay and to more accurately assess sources and sinks of fecal coliform as follows:

1) **Investigation of subsurface fecal coliform maximum in winter in Inner Bay:**
Priority: High

Although well defined as to temporal occurrence, the source or cause(s) of subsurface maximum of fecal coliform bacteria in Inner Dungeness Bay in the winter remains a mystery. Understanding this phenomenon is important for dealing with the critical winter season fecal coliform problem. Two concurrent approaches are recommended; one method using molecular identification tools, the other using a refinement of previously used water and sediment sampling methods. Either one approach or the other or both could be conducted.

1a) Molecular: Relative Costs: High

For the molecular approach, some type of genetic fingerprinting or DNA ribotyping could be targeted at suspected primary contributing species. This would include seals, diving ducks and dabbling ducks and possibly geese. This type of sampling can be very expensive as a library of genetic material has to be developed site-specifically and involves extensive laboratory assessments and cataloguing. As funds would likely be limited, a deductive approach could be used, i.e., only sampling of Inner Bay wildlife. If the results show other species dominating, it would either be from gulls at the river mouth or in-river sources. Ideally, the entire system would be monitored, but that would be prohibitively expensive.

1b) Refinement of existing methods: Relative Costs: Moderately Low

In this approach, an investigator would examine sediment quality in the Inner Bay during the critical winter season, particularly in fine sediment areas of the bay. Concurrently, vertical profiles at several depths would be collected for fecal coliform measurement, not just surface and subsurface as was done in the present study. In addition to normal MPN assessment, sample splits of subsurface water would be bioassayed using varying light levels in vitro or in open containers with typical light attenuation filters used in phytoplankton light dynamic studies. Reduced light in subsurface water depths in the winter is thought to be a key factor in the possible extended survival and accumulation of fecal coliform. Another option would be to examine dilution effects of distilled water on subsurface water sample FC bacteria. This would involve mimicking the reduced surface salinity that often occurs during high river flow periods in the winter.

2). Elucidation of wildlife effects dynamics (In part repeated from Phase 1)
Priority: Moderate, Relative Costs: Moderate

The scientific literature may adequately describe fecal coliform production rates for many types of animals, but the disposition rate and short-term physical fate of the fecal matter and associated fecal coliform in the water column is poorly understood. A combination of extended literature searching, personal contacts with other researchers worldwide and field studies will be needed to address these issues more fully. Field data collection would include estimation of sinking rates of bird and seal fecal matter, by collection of fresh samples on shore from intertidal areas and dispersion into the water. This type of study could also be done with tall glass cylinders, although there are physical edge effects of such a system. Alternatively an inexpensive limno-corral (perimeter skirt around a small ring float) assembly could be used for these in vivo experiments to remove the effect of lateral currents. Another related task would be to measure the relative solubility of differing species fecal matter, with or without concurrent fecal coliform estimates. Use of the existing subsurface Zobel sampling device would be useful in this regard.

3) Compilation of Outer Bay circulation data

Priority: Moderate, Relative Costs: Low

Extensive outer bay drogue data have been collected in phase 2, but only some of these data have been analyzed. Data were collected on various tidal ranges and timings, but time limitations prevented a complete assessment of the data. Analysis of these data would result in a set of circulation maps similar to those prepared for the Inner Bay in the Phase 1 studies.

4) Nutrients, Algae and Stratification

Priority: Low, Relative Costs: Low

Extensive vertical profiles were collected during the study year using a multiprobe CTD that include a Turner SCUFA fluorometer that measures in vivo chlorophyll a concentrations. That is an accepted surrogate measure of phytoplankton density. Additionally, some phytoplankton and nutrient data were collected and some of each has been analyzed in the laboratory. There are indications from these data that Inner Dungeness Bay is nutrient sensitive, but the data require further analysis and comparison before trends could be determined. As tidal, weather and other data from the study year have already been analyzed and entered into spreadsheets; completion of this task would help round out understanding of some of the basic biological facets of the bay. A few additional samples would be collected during spring to identify and possibly culture the unknown microflagellates that were so abundant at the same time in 2002.

5) Bird Population Dynamics

Priority: Low, Relative Costs: Low

Further information regarding gull and duck populations in the eastern Strait are available from academic researchers. These data should be assessed to investigate area-wide trends and patterns of use for gulls and ducks in particular. The USFWS refuge data are probably not adequate in this regard, as it does not include gulls near the river mouth that sometimes constitute a major effect on water quality. Discussions could be held with other agencies to seek a means to monitor the populations and track fecal coliform effects on the bay and shellfish harvesting. There may also be a need to begin tracking gull numbers periodically in the river mouth area, for as noted above, this has not been done in the past.

6) Seal Haul Out Relocation Investigation

Priority: Medium, Relative Costs: Low

Harbor seal fecal coliform loading appears to be nearly non-existent in the Inner Bay and river mouth areas during the critical winter season due to the near complete absence of seals in those areas in that season. However, in the summer the seals have significant effect, ~11% or more of the total Inner Bay FC loading. Cline Spit Island is a crowded habitat for seals and birds, nearly disappearing at a very high tide. This task would involve investigating the possibility of locating a log raft haul out system in the Outer Bay in the lee of the main spit and within the boundaries of the wildlife refuge. This approach has been used in other areas with some apparent success (Calambokidis et al. 1990). The system would be designed to attract seals from the Cline Spit area, but would be abandoned if it just relocated seals from the main spit. From other studies and estimates, a raft or series of rafts would not need to be large and could utilize readily available materials such as log rafting “boom sticks”. The investigation would review other relocation attempts, involve various government agencies and staff and lay out the necessary steps and permits involved.

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11 APPENDICES

Appendix A. Revised Circulation Summary

Note this section is repeated and slightly modified from the Phase 1 report. Detailed drogue plots were presented in that document and are not repeated here.

Sampling Scheme and Rationale

There have been no prior studies of circulation within Dungeness Bay, although Swartz et al. (1987) made estimates of maximum transport rates of 48 to 60 cm/sec in the main channel leading into the inner bay, based on very limited drogue studies. They noted that flood tide waters "were carried either to the west through the breach in Cline Spit or northward, west of Graveyard Spit…". They also provide references suggesting that Cline Spit was breached in 1978 created the Island we refer to as Cline Spit Island, herein.

The sampling plan and rationale to assess circulation was elaborated in detail in the Phase 1 Quality Assurance and Procedures Plan. In general it involved selecting certain days that had average or extreme tidal exchange. Emphasis was placed on sampling the Inner Bay as that was the area to be modeled. In order to maximize work in daylight hours in the year 2000, sampling was restricted to the May through September period. Drogues were constructed to allow use in varying depths including the shallow water areas of the Bay.

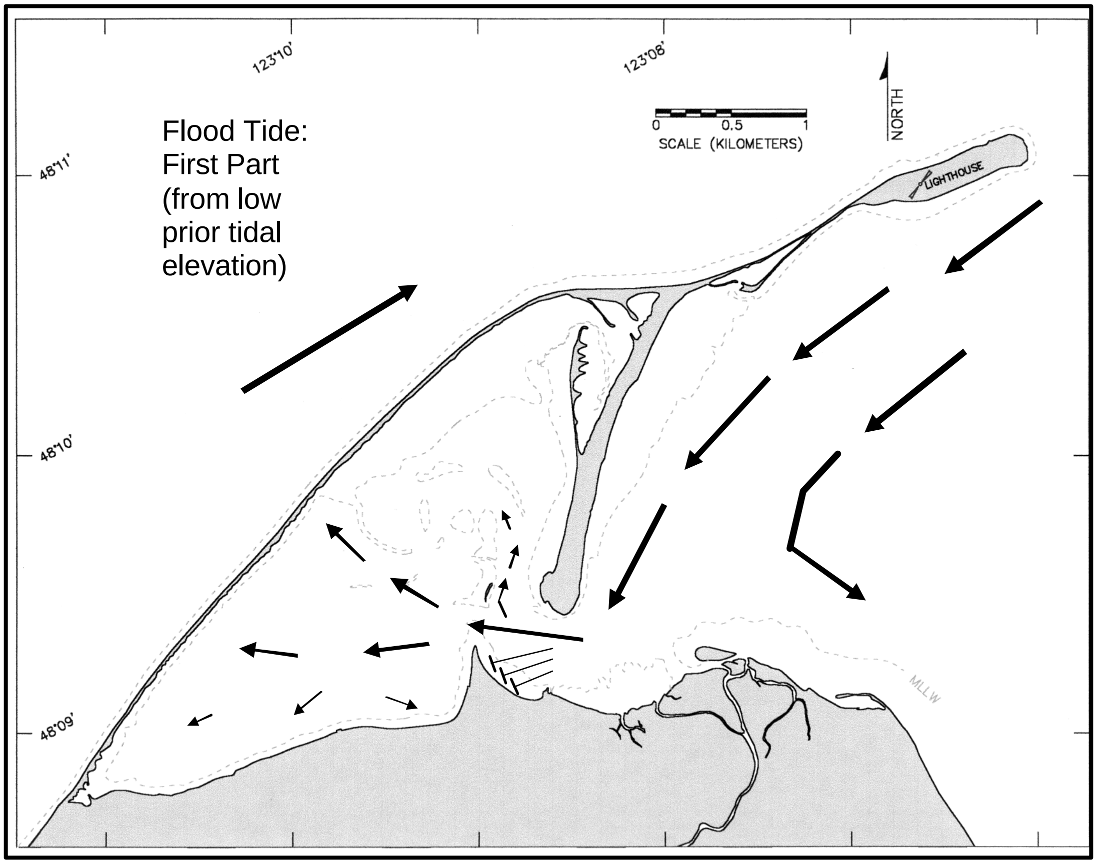
Generalized Results

This section presents a series of generalized figures that represent composite drogue survey results given in the Phase 1 final report (Rensel and Smayda (2001). Besides providing illustrations of general circulation patterns, these plots can be compared to tidal excursion information, salinity data and other information to help illustrate relative rates of water and fecal coliform transport within the study area. Each figure has varying sized arrows to generally represent the rate of transport during a particular stage of the tide. Most of this information is directly drawn from my drogue measurements and personal observations. I have focused primarily on the Inner Bay, but include information to generally describe patterns in the Outer Bay and beyond. See also the *Reflux of Inner Bay Water* section of this report for more information on drogue results.

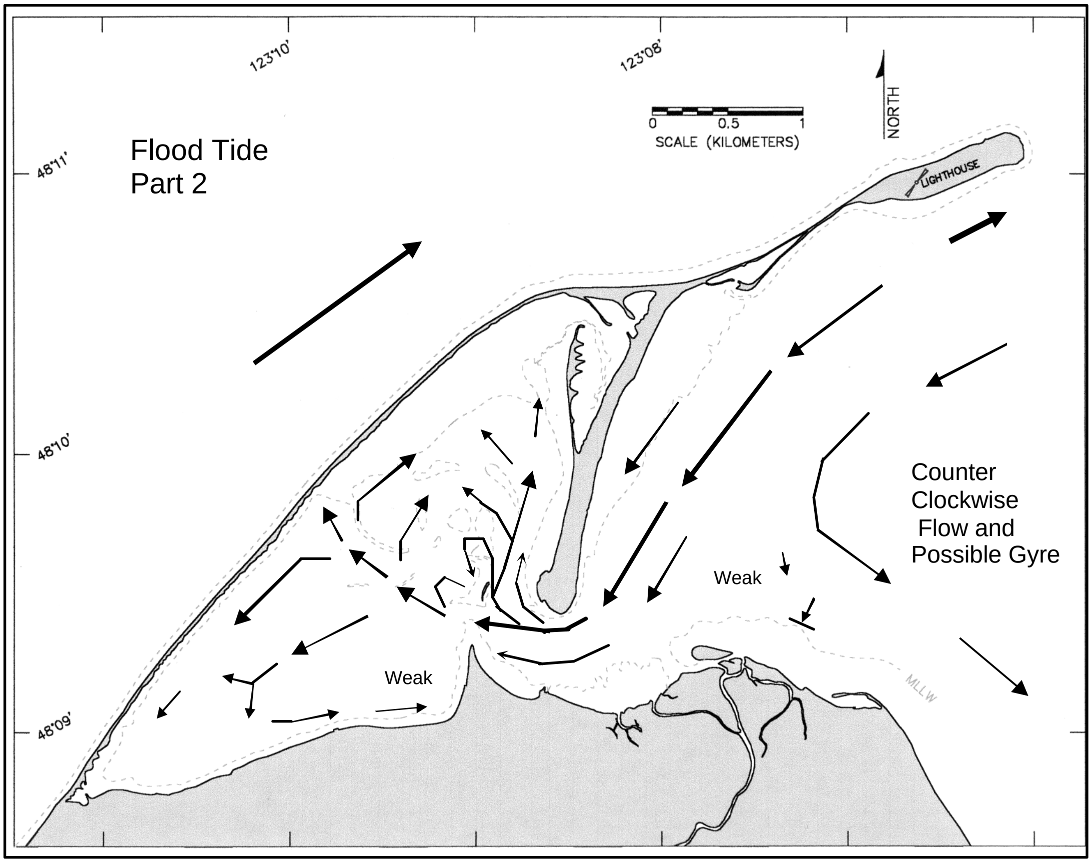
Flood Tide, Inner Bay

Appendix Figure 1 shows the general flow patterns during the onset of a flood tide when tidal elevation is relatively low, i.e., < 0.3 m elevation (above MLLW). The primary aspect of tidal flow into the Inner Bay at this stage of the tidal cycle is that the bulk of the water that enters the Inner Bay passes via the relatively shallow but wide passage between Cline Spit Island and Cline Spit. As previously discussed, the large western or main basin of the Inner Bay is both deeper and broader with more volume than the northern portion of the Inner Bay. Therefore, at the early stages of the flood tide, from a suitably low tide, inflowing water seeks to fill this main basin area more rapidly than the northern areas of the Inner Bay (e.g. compare Appendix B, pages 7-10 versus pages 11-12 in the phase 1 report). This key aspect of circulation is demonstrated by comparing other flood tide drogue paths with those of June 6th (Phase 1 report, appendix B, pages 15-17, although these plots show later phases of the flood tide). This has significant implications regarding the riverine load of fecal coliform, as the river water that has pooled up near the Entry Zone and much of the early flood tide river water is forced directly through Cline Spit Pass into the Inner Bay.

The May 1, 2000 flood tide began at 1.9’ elevation and did not display the above-mentioned shift in flow pattern. On June 6th, however, the flood started at –0.6 m, and most of the incoming drogues went due west through the Cline Spit passage until later in the tide. Late in the flood tide of June 6th, most of the drogues released in the main channel of the outer Bay flowed past the tip of Graveyard Spit and turned north into the channel east of Cline Spit Island, further supporting this general conclusion. Similar results occurred on July 12th that started at a relatively low elevation of 0 m (MLLW). Generalized water flows during the second part of the flood tide or when the flood tide starts from a higher elevation are shown in Figure 1.



Appendix Figure 1. Initial flood tide circulation when elevation of preceding low tide is relatively low, e.g., a three-hour period with the tide rising from 0.3 to 1.0 m. Perpendicular lines at arrow ends indicate down-welling based on drogue groundings on the beach.



Appendix Figure 2. Flood Tide, second half from low tidal elevation or when extreme low tide elevation is no less than about 0.3 m More information was available to the east and south in the outer Bay, showing extension of the same pattern.

The deep part of the channel immediately east of Cline Spit Island has rapid rates of water transport at most times the tide is running, but depths shoal rapidly in this channel to the east, partially restricting inflow at lower elevations of flood tide. The smaller arrows in Appendix Figures 1 and 2 indicate this difference, although by the end of the flood tide the Northeast Inner Bay is being rapidly inundated which allows for proportionately greater flow. Note that at all times during the flood tide (and with westerly winds ranging up to 10 knots) that water in the area immediately west of Cline Spit to the south shore moves weakly to the east. As discussed later, this occurs also during ebb tide too and is undoubtedly accentuated by the predominant westerly winds from Spring to Fall.

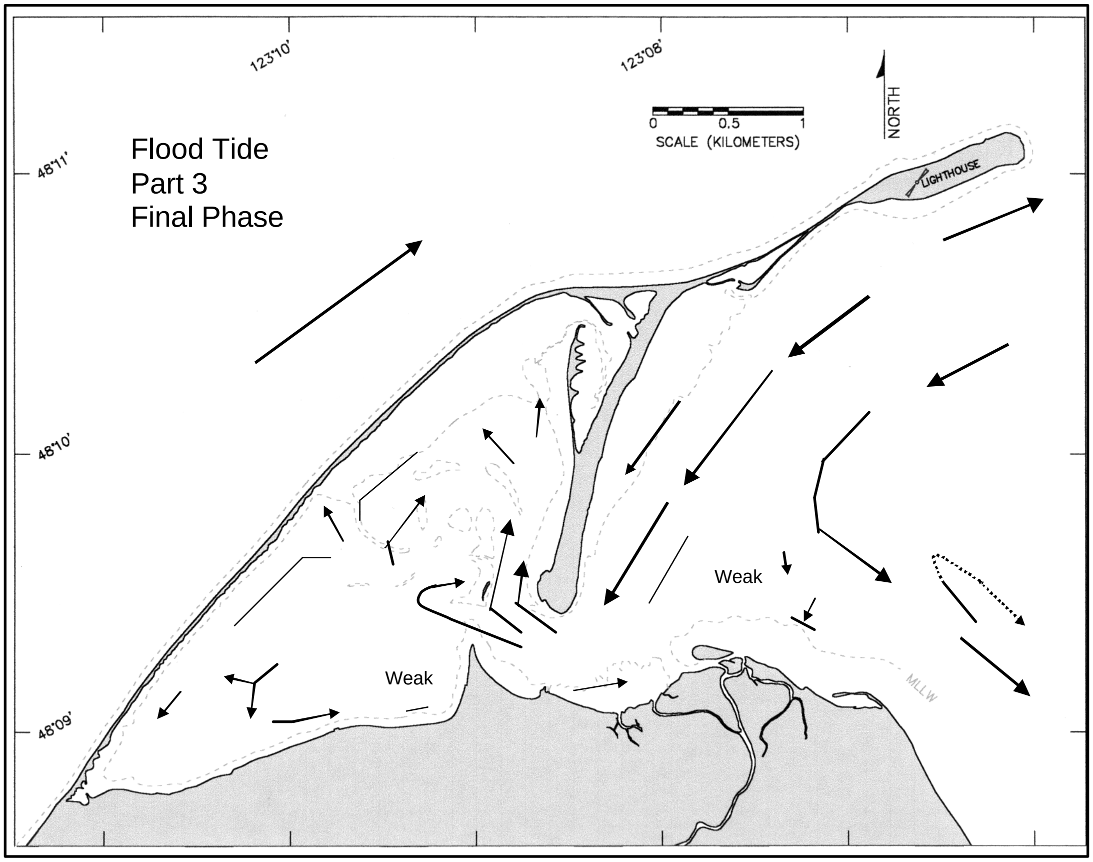
During the second half of flood tide, water flow into the channel between Cline Spit Island and Graveyard Spit increases (Appendix Fig. 2), which was demonstrated by the change in drogue distribution. While this is not a startling observation on its own, the effects of this split of inflowing water between the two entries to the Inner Bay is to create a previously unknown convergence zone to the west of Cline Spit Island. We repeatedly found that drogues would enter this area to the west of Cline Spit Island and become trapped in a large (ca. 500 m diameter) zone of slow circulation for up to 4 hours. Sometimes the drogues would stay in the general area throughout the balance of the flood tide; at other times they would move slowly about for a while then be ejected, to then move slowly south and be caught up in the swift, westerly tidal stream that flows in the breach between Cline Spit and Cline Spit Island. The convergence zone is of interest, as it tends to trap water from both sides of Cline Spit Island that could include river water and wildlife fecal matter with fecal coliform. It is a phenomenon that did not exist prior to the breaching of Cline Spit, and represents a "short circuit" in the flow patterns that in part may help explain the necessity of the recently expanded shellfish closure area.

Toward the end of the major flood tide (e.g., July 12, 2000), or at the end of a small flood that began at a moderately high elevation (September 17, 2000), most of our drogues from the cross channel arrays south of the tip of Graveyard Spit flowed north, in the passage between Cline Spit Island and Graveyard Spit (Appendix Fig. 3). This was somewhat unexpected but occurred when nearshore waters were already beginning to ebb. Appendix Figure 3 is presented primarily to show this phenomenon. Circulation patterns in other areas at this tidal stage are believed to be somewhat similar to Appendix Figure 2, but reduced in rates of volume transport. We documented the continuation of flow into the convergence zone to the west of Cline Spit Island, but only from the south side. It may continue to the end of the flood on the North side too, but we had no drogues in that area at those times.

Flood Tide: Outer Bay

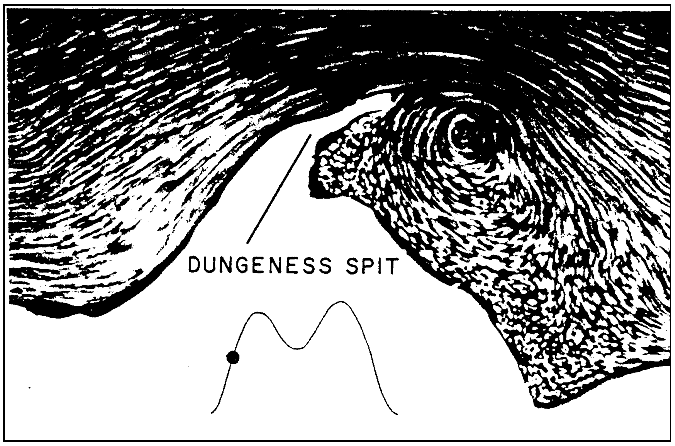
Initially I thought that the majority of water exchange in the Outer Bay occurred through the "main channel" with a southwest direction of flow to the Inner Bay during the flood tide. This flow was characterized as having fast transport rates shown on every flood tide event (Appendix Figs. 1, 2 and 3). Water follows the deeper portions of the main channel and was tracked from an area near the New Dungeness lighthouse. The shallower portions of the outer Bay sometimes also have rapid flow rates, but not always, and a recurring trend was for the main flows to occur parallel to the contour lines. However, several days of drogue studies conducted to determine reflux rates for the Phase 2 study indicated that much of the ebb tide water was exiting to the south of the main channel. Thus the main channel may be more important during flood tide only, but clearly bottom sediments are coarse, current speeds fast and these factors are indicative of high rates of water exchange.

Another feature of Outer Bay flood tide circulation that is particularly important to this study is the splitting of southeasterly flowing flood tidal flows. While some of the flow traveled via the main channel towards the Inner Bay, a major diversion to the south and then to the east occurred along the Three Crabs Beach area. Initially we believed this to be part of a major, counterclockwise gyre in the Outer Bay, but this would be unexpected given the easterly direction of flood tides in the Strait of Juan de Fuca main channel. We then re-examined our drogue path data and previously measured outer Bay bathymetry and prior hydraulic tidal modeling of the outer Bay area by Ebbesmeyer et al. (1979) that focused mainly on Port Angeles Harbor. This reconsideration led us to believe that our drogues were simply reflecting the water flow following major bathymetric contours, and there was no evidence of a gyre in the Outer Bay, within our study area. An exception is the area near the Lighthouse near the end of the main spit. Here in the Phase 2 study we found repeated occurrence of west to east flow, potentially part of a clockwise gyre. As shown in Appendix Figure 4 from the hydraulic tidal model of Ebbesmeyer et al. (1979) there is likely a clockwise oriented gyre much further to the east during the flood tide, but not within our study area. But that information is from a scale model that may or may not represent conditions as they actually occur.



Appendix Figure 3. Flood tide, final phase and beginning of ebb tide. Estimated path indicated by dotted line.

Much of the Outer Bay flood tide circulation information in the Phase 1 study of year 2000 was restricted to the first two field days, so our data there is less complete than for the Inner Bay. However, as part of the reflux surveys in phase 2, we were able to make additional Outer Bay

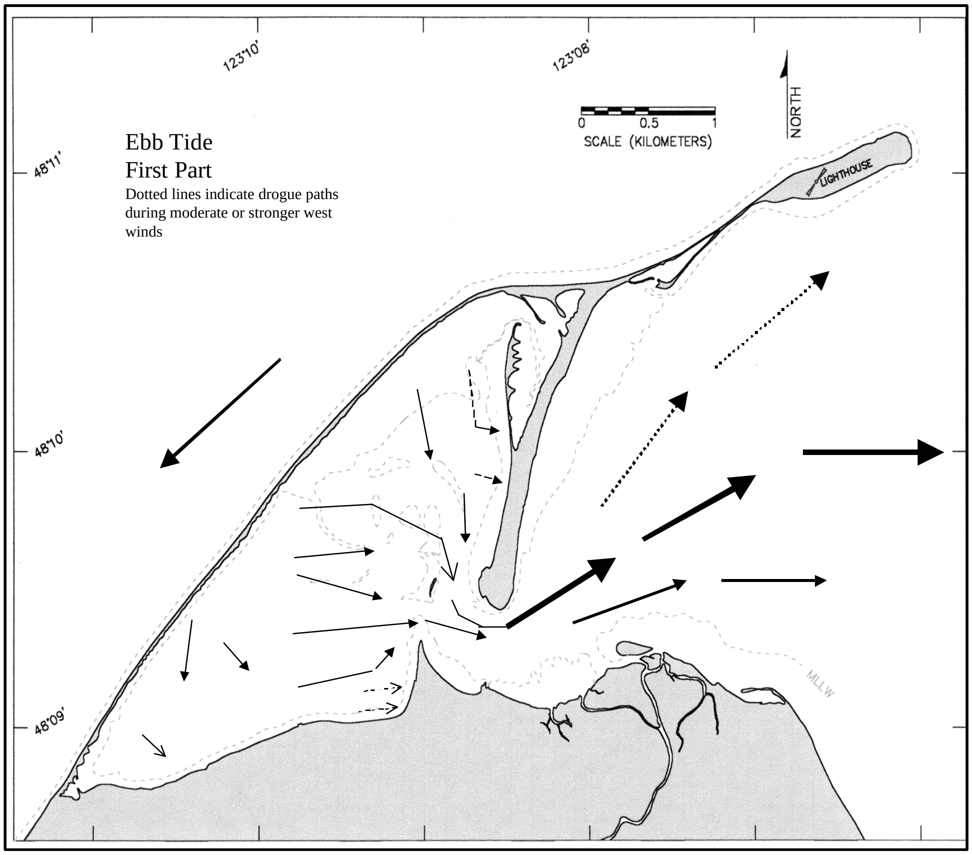


Appendix Figure 4. Clockwise flood tide gyre in area east of Outer Dungeness Bay from Ebbesmeyer et al. (1979). This physical model did not have an accurate depiction of the Inner Bay, but shows the center of the gyre in the right center and surrounding circular flow patterns. The true extent of the gyre nearer the shoreline is best determined through additional drogue studies.

Ebb Tide: Inner Bay

Ebb tide patterns in the Inner Bay were somewhat the inverse of the flood tide, with the exception of the weakly flushed area west of Cline Spit to the south Shore. In general, water from the northern areas flows due south to the entryway, via the passage to the east of Cline Spit Island. Water from the western portions of the main basin flows through the Cline Spit Passage, and the central portions of the Inner Bay flow more or less equally through both passages, with a bias toward the passage east of Cline Spit Island early in the ebb (Appendix Figs. 5 and 6). Wind effects occur throughout the Bay, as discussed above in the flood tide section, depending on the velocity and temporal extent.

During intermediate stages and elevations of the ebb tide much the same pattern of flow exists, except the volume of water remaining in the northern areas of the Inner Bay has been reduced significantly, and proportionately more flow is occurring through the Cline Spit Passage. Also, we noticed repeated groundings of drogues along the west shore of Cline Spit to the south shore area, which may have been due to a pattern of increasing winds in the afternoon of some ebb tide days. As seen in the Appendix B of the phase 1 report, by design we had more information for flood tides than ebb tides, so no third figure for the ebb is warranted here.

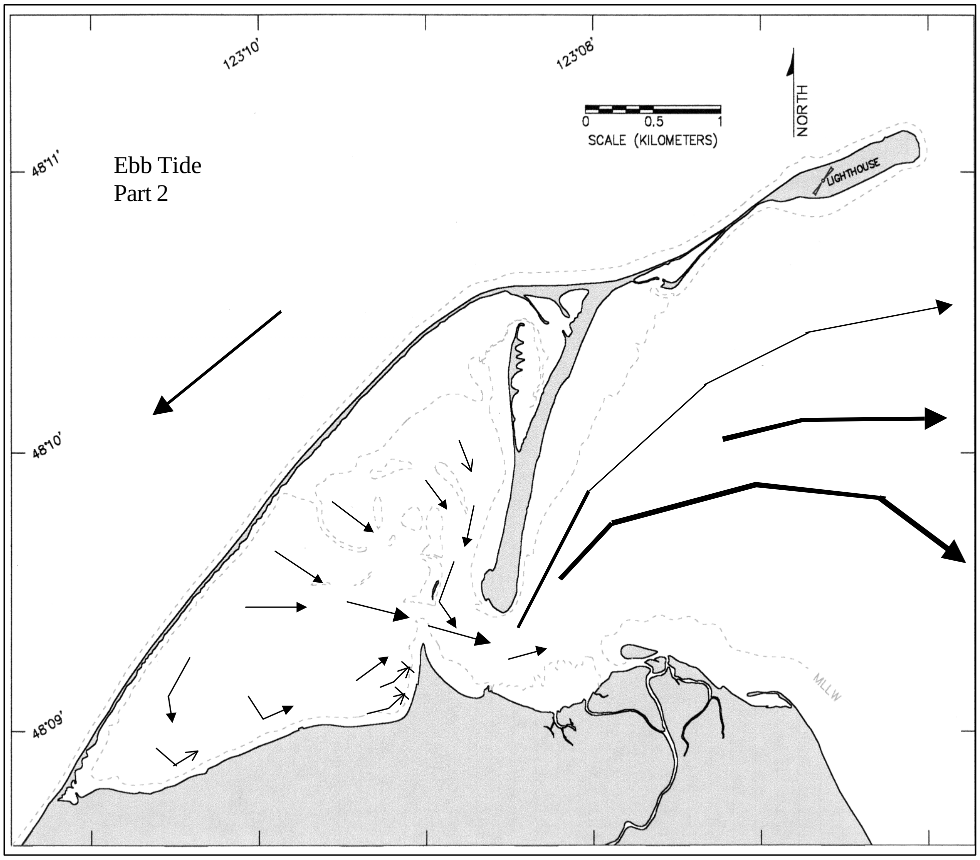


Ebb Tide
First Part
Dotted lines indicate drogue paths during moderate or stronger west winds

Appendix Figure 5. Ebb tide circulation, early periods of tide.

Ebb Tide: Outer Bay

Enough information was acquired in both phases of this work to indicate a very strong tendency for Outer Bay water to flow to the southeast and sometimes east. In general drogues drifted from the entry to the Inner Bay to the east, tending to move southeast in the more easterly areas. When the sea surface elevation is relatively high, the outflowing tide freely flows across the broad and shallow Outer Bay flats, generally parallel to the depth contours. When the water level is lower, for example < MLLW, then much more water flows through the main channel, because the shallower areas offer substantially greater resistance to flow or simply are not inundated. As previously discussed, the river plume during ebb tide may be found in central and southern parts of this outer Bay zone.



Appendix Figure 6. Ebb Tide Circulation, later stages.

Some Implications of Observed Circulation Patterns

Prior to a flood tide, river water from the prolonged slack tide period (often ~ 1 hr) that is “pooled up” near the river mouth and Entry Zone enters the Inner Bay via the Cline Spit passage and passes to the main basin of the Inner Bay. This river water tends to be layered over and mixed to varying degrees with the incoming seawater but is in general restricted to the southern portions of the Entry Zone to the Inner Bay. The main thrust of seawater entering from the Outer Bay clearly dominates the north and center areas of the entry area (i.e., the channel south of the south tip of Graveyard Spit). A combination of slight shoaling in the Entry Zone passages and orographic funneling of the spring to fall predominant west wind at this point (Harris and Rattray 1954) causes a rough patch of water during many flood tides that sometimes appear like a river rapids. This turbulence causes vertical mixing in the water column, resulting in significant dilution of the river plume. A partial exception may be at higher tidal elevations, when turbulence and winds are less, and the extent of this sort of mixing is less.

Opposing wind and tides in other marine channels commonly produce such rough water patches, for example off Point Wilson near Port Townsend. Although a detailed discussion of wind in the study area is beyond the scope of this study, about 1 to 2% of all observations in the Port Angeles/Dungeness Bay region showed strong northeasterly winds that may have significant effects on beach forming processes, but are much less important in forcing the location of the unmixed river plume (Cannon 1978). In our winter time sampling of year 2001-2002 we noted many days of strong due easterly winds in Dungeness Bay. The wind wasnot northeasterly, but due easterly. We observed the rough patches near Cline Spit Passage on both easterly and westerly wind events, and during strong tidal exchange periods. Swartz et al. (1978) made general observations regarding circulation and mixing in the bay concluding that “water in the west and east Dungeness Bay (i.e., inner and outer bays) appears to be well-mixed by tidal action with surface salinities in both sections of the bays ranging from 26 to 32 ppt”. Further they noted “ water clarity was best in the deeper eastern part of Dungeness Bay, whereas the western part, though shallower, had more turbid water. The strong tidal currents through the inlets would seem to play a major role in causing this difference”.

The observed turbulent and probable mixing area likely varies with the strength of the wind and stage/speed/volume of the tidal flow, but as the tides recur daily I believe this mixing is frequent enough to be responsible for some of the observed lower fecal coliform values in the Inner Bay. The reader is reminded that sampling for fecal coliform by the Department of Health is restricted by protocol to 8 inches deep, and we found significant differences in coliform vertical distribution in the Inner Bay during the phase 2 studies.

Wind effects on water transport in the Inner Bay are most pronounced during and near slack tide times and probably help establish a counter current flow along the south shore of the Inner Bay near the west shore of Cline Spit (Appendix Fig. 2). Drogue movement rates in this area, which includes the Old Town to Cline Spit boat launch and Gun Club areas, were relatively slow regardless of tidal amplitude. The seasonally predominant westerly wind enhances the easterly set in this area.

During the middle and latter portions of the flood tide, our drogues and salinity measurements suggest that some portion of the river plume begins to flow northward through the channel between Cline Spit Island and Graveyard Spit. But as the river plume in the channel south of Graveyard Spit is typically restricted to the south to at most middle regions, it is probable that the larger fraction of river water ends up flowing into Cline Spit Passage. An exception to this would be at the end of the flood tide, as shown on July 12th 2000 when all 5 drogues released in a cross-channel array south of Graveyard Spit moved north into the channel east of Cline Spit Island. We observed low salinity water in this area and to the north in this channel on several occasions, and we believe west winds tend to push surface waters, including less saline river water, toward the east. This pattern may be verified by the common sense observation of large amounts of flotsam on the beach along the west side of Graveyard Spit.

Ebb tide circulation patterns in the Inner Bay show a reversal of flood tide patterns, with the exception of the weakly flushed area just west of Cline Spit near the boat launch referred to as the Cline Spit Gyre. This area usually experiences slow flushing and consistent counterclockwise movement of water, impinging on the beach in many cases through the additive force of the westerly wind when present. A lack of any high fecal coliform values in this area except in winter and near outfall of irrigation ditch returns suggests that either water exchange rates from the outer Bay and river are very slow, providing ample time for fecal coliform die-off, or that mixing at the Cline Spit Passage entry dilutes the signal. We believe it is a combination of these factors that generally maintains this area within FC standards, but there are periods in the winter when riverine or irrigation ditch water or fecal coliforms from wildlife will be retained in this area and result in relatively high fecal coliform testing results.

Finally, it is emphasized that circulation in the Inner Bay has changed substantially since the breaching of Cline Spit that occurred approximately in 1978 (Swartz et al. 1987). Before that event, all flood and ebb water entered through the single passageway just west of the tip of Graveyard Spit. The breaching of the spit now allows substantial volumes of water, and much of the flood tide carried river water, to enter the main basin of the Inner Bay directly during middle and late phases of the flood tide.

Appendix B. Geometric mean fecal coliform by season and depth class (surface versus subsurface), temperature, salinity and turbidity. OB = Outer Bay, CS = Cline Spit

	Depth Class	Mean Depth	N	Geometric Mean FC	Temp. (C)	Sal. (psu)	Turb. (NTU)
Nov - Feb season							
Offshore in Strait	Shallow	0.1	5	1.0	7.9	30.91	4.8
	Deep	10.0	4	1.4	8.0	31.38	2.0
OB near Lighthouse	Shallow	0.1	6	2.1	8.0	29.97	8.6
	Deep	10.0	4	1.0	8.0	30.90	4.5
OB Main Channel E.	Shallow	0.1	3	6.0	7.5	24.41	28.7
	Deep	4.0	3	1.8	8.2	31.29	8.9
OB center	Shallow	0.1	3	2.2	7.2	25.09	36.3
	Deep	8.0	3	1.6	7.7	30.97	6.5
OB Main Channel W.	Shallow	0.1	11	4.7	7.6	28.14	5.8
	Deep	2.8	7	4.2	7.7	30.40	6.4
RV Mouth	Shallow	0.1	7	10.1	5.9	11.82	82.8
	Deep	0.8	6	4.7	7.2	22.32	88.8
Area 2.1 Near Rv. Mouth	Shallow	0.1	7	4.7	8.0	28.72	15.5
	Deep	2.5	5	9.3	8.2	30.28	7.5
Area 3.1 Entry Zone	Shallow	0.1	18	6.9	7.8	27.56	26.9
	Deep	3.9	17	4.3	7.9	30.35	8.1
Area 3.2 Convergence	Shallow	0.1	7	5.5	7.6	26.72	16.3
	Deep	3.4	7	7.8	7.7	29.84	11.0
Area 4.1 Inner Bay W.	Shallow	0.1	17	4.3	7.9	27.97	12.8
	Deep	3.1	16	22.8	7.8	30.52	8.9
Area 4.2 C.S. Gyre	Shallow	0.1	5	4.3	7.2	28.17	6.9
	Deep	2.8	5	25.6	7.3	30.18	10.1
Area 4.3 North Basin	Shallow	0.1	5	2.2	7.4	25.27	26.0
	Deep	3.9	5	7.6	7.8	30.58	5.7
Mar - July Season							
Offshore in Strait	Shallow	0.1	8	1.1	9.3	30.86	1.1
	Deep	5.6	8	1.1	9.2	30.98	1.3
OB near Lighthouse	Shallow	0.1	7	1.6	8.8	29.15	4.9
	Deep	5.0	7	2.1	9.1	31.09	1.2
OB Main Channel E.	Shallow	0.1	9	2.4	10.5	29.92	6.5
	Deep	3.6	8	1.5	9.0	30.97	2.6
OB center	Shallow	0.1	5	1.0	10.8	30.92	3.3
	Deep	4.6	5	1.3	9.5	31.38	1.7
OB Main Channel W.	Shallow	0.1	2	9.2	10.1	10.35	
	Deep	1.0	1	4.0	11.1	30.40	
RV Mouth	Shallow	0.1	27	8.9	10.4	4.75	54.7
	Deep	0.7	5	2.9	11.4	21.85	28.3

	Depth Class	Mean Depth	N	Geometric Mean FC	Temp. (C)	Sal. (psu)	Turb. (NTU)
Area 2.1 Near Rv Mouth	Shallow	0.1	1	2.0			
	Deep	3.0	1	2.0			
Area 3.1 Entry Zone	Shallow	0.1	16	1.6	11.4	27.46	6.6
	Deep	2.8	16	1.4	11.1	30.32	5.8
Area 3.2 Convergence	Shallow	0.1	18	4.2	11.2	26.75	6.3
	Deep	1.4	12	3.1	11.4	29.66	8.6
Area 4.1 Inner Bay W.	Shallow	0.1	26	1.8	12.1	29.44	7.2
	Deep	2.1	28	2.5	11.4	28.49	35.2
Area 4.2 C.S. Gyre	Shallow	0.1	8	2.6	12.4	29.84	6.5
	Deep	2.0	6	2.0	12.1	30.36	9.0
Area 4.3 North Basin	Shallow	0.1	8	1.5	11.6	30.25	5.2
	Deep	2.4	7	1.9	11.4	30.17	6.2
Aug - Oct Season							
Offshore in Strait	Shallow	0.1	4	1.0	10.4	31.72	0.2
	Deep	6.3	4	1.0	10.0	31.88	0.2
OB near Lighthouse	Shallow	0.1	6	1.0	9.7		0.2
	Deep	7.5	4	1.0	9.6	32.25	0.1
OB Main Channel E.	Shallow	0.1	4	1.4	11.2	31.60	0.6
	Deep	3.3	3	1.4	10.1	32.21	0.3
OB center	Shallow	0.1	3	1.0	12.2	31.01	0.0
	Deep	5.0	2	1.0	10.3	31.41	0.2
Rv. Mouth	Shallow	0.1	3	8.4	10.5	20.44	1.8
	Deep	0.6	4	2.3	12.4	27.45	2.2
Area 2.1 Near Rv Mouth	Shallow	0.1	16	20.9	16.1	1.93	0.9
	Deep	0.6	4	2.3	12.4	27.45	2.2
Area 3.1 Entry Zone	Shallow	0.1	11	1.1	12.2	30.01	1.1
	Deep	3.3	12	1.5	11.6	31.38	1.6
Area 3.2 Convergence	Shallow	0.1	11	1.8	13.9	27.91	3.2
	Deep	1.7	9	1.5	12.7	31.08	4.4
Area 4.1 Inner Bay W.	Shallow	0.1	13	1.1	13.8	30.61	3.9
	Deep	2.3	13	1.1	12.8	30.79	8.1
Area 4.2 C.S. Gyre	Shallow	0.1	6	2.5	14.9	30.00	6.4
	Deep	2.0	3	1.6	13.7	30.56	7.3
Area 4.3 North Basin	Shallow	0.1	2	1.0	13.4	31.60	1.6
	Deep	4.0	2	2.0	11.6	31.73	0.9

Appendix C. Dungeness River near mouth discharge data, 2001-2002 from Washington Department of Ecology provisional data.

See Below for interpolated version
Station 18A050 Dungeness River near mouth Year 2001/02
VarFrom 232.00 Raw Stage in Feet Table Type Rate
VarTo 262.00 Discharge in Cubic feet/second, Measured
Figures are for period ending 2400 hours.

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	76.4	275	530	334	284	394	278	370	759	672	252	132
2	70.8	223	701	872	268	360	280	455	698	582	220	131
3	67.9	198	471	914	266	333	271	489	684	530	204	135
4	64.5	177	376	698	259	317	270	459	675	503	190	134
5	60.7	191	335	584	257	305	291	423	873	470 []		128
6	59.7	177	317	698	269	281	334	384	1020	448	179	124
7	59.8	161	294	3950	317	271	347	354	840	459	171	134
8	59.8	147	372	4400	302	263	331	322	664	512 []		122
9	57	139	472	2170	271	254 []		299	544	546 []		115
10	58	132	392	1500	261	258 []		283	516	526 []		109
11	71.1	133	359	1170	264	452 []		265	592	651 []		112
12	65.7	265	326	1070	242	612	378	270	720	662 []		109
13	71.7	403	413	906	231 []		420	324	850	583 []		109
14	74.9	1410	957	774	214 []		1140	412	1050	617 []		107
15	73.5	2330	650	658	204	384	1180	396	1130	533 []		107
16	71.7	1420	1990	581	210 []		807	373	1050	483 []		115
17	71.6	825	3350	515	215 []		645	381	919	499 []		146
18	66.5	589	1440	479	215 []		526	394	878	484 []		137
19	67	758	969	462	254	281	466	387	793	472 []		130
20	69.5	1900	752	437	269 []		432	386	674	450 []		128
21	67.5	1410	625	413	734 []		417	424	682	408 []		125
22	85.9	1070	540	386	2120 []		410	462	786	385 []		122
23	161	853	472	359	1610	292 []		454	849 []		140	119
24	128	691	413	351	1040 []	[]		445	811 []		140	115
25	115	586	383	424	728 []		359	457	787	399	141	112
26	125	490	361	391	570	370	346	570	925	394	153	111
27	299	416	350	357	482	361	345	703	993 []		147	109
28	227	402	354	333	437	330	318	824	984 []		138	108
29	171	444	341	307		303	303	1110	1060 []		135	109
30	148	387	326	302		289	315	1080	871 []		137	108
31	316		324	300		278		889	[]		135	
	103	620	644	874	457	333	448	479	823	511	165	120
Mean	103	620	644	874	457	333	448	479	823	511	166	120
Median	71.6	409	413	515	268	305	347	412	825	501	147	117
Max.Daily	316	2330	3350	4400	2120	612	1180	1110	1130	672	252	146
Min.Daily I	57	132	294	300	204	254	270	265	516	385	135	107
Inst.Max	425	2810	5690	6280	2300	720	1650	1310	1240	744	270	151
Inst.Min	48	126	278	292	200	244	253	246	485	360	130	103
Missing Da	0	0	0	0	0	10	5	0	0	7	16	0

Summaries ------------------ Notes ------------------
--------- All recorded data is continuous and reliable
except where the following tags are used...

Summaries	
Annual Mean	482J
Ann. Median	361J
Missing Days	38

! ... Data not yet checked
J ... Estimated Data
[ ] Data Not Recorded
~ ... Provisional data

Appendix D. Irrigation ditch outfall fecal coliform sampling results in cfu/100ml as daily means or single observations.

	Ditch Outfall Number					
Date	**1**	**2**	**3**	**4**	**5**	**7**
9-Oct-01	746.0					
20-Nov-01	18.0	246.0		1320.0		178.0
7-Jan-02	5000.0	1540.0		5000.0		4400.0
4-Feb-02	178.0	68.0		2.0		1540.0
20-Feb-02	170.0	16.0				210.0
20-Feb-02	142.0					1.0
18-Mar-02	4.0	168.0		4400.0		130.0
15-Apr-02	102.0			660.0		244.0
15-Apr-02						1320.0
22-Apr-02	6.0		6.0			
30-Apr-02	14.0			8.0	10.0	22.0
6-May-02	18.0		142.0		2.0	4.0
13-May-02	42.0	22.0	92.0	34.0	368.0	
23-May-02		134.0	86.0	2.0	104.0	
10-Jun-02	109.0			1.0		1.0
26-Jun-02		113.0	480.0	500.0		71.0
15-Jul-02	11.0	2.0	1.0	1.4	0.4	3.0
1-Aug-02						
5-Aug-02	14.0			43.0	14.0	372.0
14-Aug-02						
22-Aug-02						
27-Aug-02	212.0			163.0	16.0	84.0
4-Sep-02						
24-Sep-02				125.0	12.0	

Appendix E. Summary of fecal coliform (cfu/100ml) sampling upstream and downstream of birds in river mouth during spring and summer, 2002.

Dominant bird category includes abundance estimate of major taxa of birds present in the immediate area, both in the river channel physically and on the banks.

Date	Relative Location	Arithmetic Mean	Geometric Mean	U - D Ratio	SE of GM	N	Dominant Birds #s
18-Mar	Upstream	1	1		1	1	10 gulls
	Downstream	17	8.5	8.5	13.9	3	
30-Apr	Upstream	36.0	35.5		8.5	2	100 gulls, 400 Brandt
	Downstream	605	347.9	9.8	700.0	2	
13-May	Upstream	29.0	28.8		4.2	2	5 gulls 50 geese
	Downstream	27.0	23.7	0.8	18.4	2	
23-May	Upstream	9.0	8.0		5.0	4	120 gulls
	Downstream	33.5	31.3	3.9	12.4	4	
10-Jun	Upstream	7.8	5.6		4.7	4	290 gulls
	Downstream	32.0	28.5	5.1	15.0	4	
26-Jun	Upstream	11.0	9.0		8.2	3	30 gulls
	Downstream	25.3	25.0	2.8	5.1	3	
15-Jul	Upstream	9.5	9.4		2.1	2	1100 gulls*
	Downstream	7.5	7.5	0.8	0.7	2	
5-Aug	Upstream	30.5	29.6		10.6	2	100 geese no gulls
	Downstream	29.3	27.7	0.9	12.1	3	
27-Aug	Upstream	15	14.8		2.6	4	150 gulls** 75 geese
	Downstream	21	18.6	1.3	10.6	9	
24-Sep	Upstream	11	10.8		2.6	3	350 gulls Many ducks
	Downstream	35	34.3	3.2	9.9	2	

* but none in river mouth channel prior to and during sampling

** gulls mostly on river bank, not in river channel