Reduced Fecal Pollution in Henderson Inlet: Remediation or Reduced Rainfall

Washington State Department of Health
Office of Shellfish and Water Protection

December 2011

Reduced Fecal Pollution in Henderson Inlet: Remediation or Reduced Rainfall

December 2011

Publication #332-100

Washington State Department of Health
Office of Shellfish and Water Protection

For more information or printed copies of this report contact:

Tim Determan
Office of Shellfish and Water Protection
Post Office Box 47824
Olympia, WA 98504-7824
Email: Tim.Determan@doh.wa.gov

PUBLIC HEALTH
ALWAYS WORKING FOR A SAFER AND HEALTHIER WASHINGTON

(This page intentionally left blank)

Page	Contents

1	Abstract
2	Introduction
3	Watershed Characterization
5	Remedial Action Summary
7	Status and Trend of Fecal Pollution in Henderson Inlet
10	Analytical Approaches
12	Results and Discussion
17	Conclusions
18	Future Challenges
20	References

Acknowledgements

The following persons contributed information, provided valuable insight, and/or reviewed the report.

- Sue Davis, Environmental Health Division, Thurston County Health Department
- Linda Hofstad, Environmental Health Division, Thurston County Health Department
- Christopher Krembs PhD, Senior Oceanographer, Environmental Assessment Program, Washington State Department of Ecology
- Owen F. Reynolds, AICP, GIS Analyst III, Thurston Geodata Center
- Kimberle Stark, Water and Land Resources Division, King County Department of Natural Resources and Parks
- Kathleen S. Whelan, District Administrator, Thurston Conservation District
- Bob Woolrich, Office of Shellfish and Water Protection, Washington State Department of Health

Front Cover Photo: Woodland Creek and Henderson Inlet, Washington State Department of Ecology, http://apps.ecy.wa.gov/shorephotos/

Abstract

Fecal pollution in Henderson Inlet decreased from “High” fecal pollution impact in 2001 to “Low” fecal pollution impact in 2009 (WDOH 2010). Remedial programs and change in rainfall patterns likely contributed to the reduction. I used three independent analytical approaches to study fecal pollution in inner Henderson Inlet and it relationship to both short-term climate fluctuations and remedial action. The three analyses strongly confirm that fecal pollution has significantly declined. Only one of the three methods measuring fecal pollution showed a weak connection with decreasing rainfall. Remedial action is difficult to evaluate directly. Observations suggest that an upturn in rainfall in 2009 did not produce an increase in fecal pollution. By inference, remedial programs are likely the dominant factor in reduced fecal pollution in Henderson Inlet.

Introduction

In 2009, the Washington State Department of Health (WDOH) identified 21 shellfish growing areas in Puget Sound that were significantly affected by fecal pollution (WDOH 2010). This number was substantially lower than the 30-35 affected areas noted in earlier years. WDOH (2010) also noted a State-wide trend toward drying conditions from 1998 through 2009 (National Climatic Data Center, U.S. Dept. of Commerce), a period that we refer to in this report as "climate fluctuation". A number of shellfish growing areas showed reduced fecal pollution during the previous decade. Some growing areas have been objects of considerable remediation. However, others were not.

At least two major factors may influence fecal pollution in shellfish growing areas. One factor is **human activity** (both negative and positive) in adjacent uplands. The other is **short-term climate fluctuation**. Henderson Inlet is the focus of this study due to its long fecal coliform data record and the high level of remedial action that has occurred there.

.

Human Activity. Negative human factors include poor land management and intensification of development. Positive factors include effective land use management and remediation, such as the following:

- Agricultural best management practices on farms and dairies.
- Repaired or upgraded individual onsite sewage systems, updated onsite regulations, "Operation and Maintenance" programs, and standards for onsite sewage system professionals.
- Rebuilt and expanded municipal sewage and stormwater collection and treatment facilities, and newly adopted stormwater management standards.
- Boat waste pumpouts and dump stations at marinas and marine parks.

We need to measure change in fecal pollution in Henderson Inlet to evaluate remedial action. However, the effect of fluctuating rainfall over time can make these determinations difficult. Drier weather means less runoff-related pollution. Ideally, we would independently evaluate the contribution of both human factors and rainfall to changes in fecal pollution.

Evaluating Remediation. Direct quantitative measurement of remediation is complex. It requires extensive standardized record-keeping and regular reporting by local agencies (health, building and planning departments, conservation districts, etc.). Standardized documentation is rudimentary in most jurisdictions. Existing information tends to be sparse, intermittent or inaccessible. The remaining information tends to be anecdotal and subjective, and thus, inherently inaccurate. Without clear measures of remediation, we must measure its effect indirectly by evaluating the importance of the second factor, short-term climate fluctuation.

Rainfall patterns. Rainfall is the major driver of runoff. Runoff carries fecal coliform pollution from upland sources into streams and drainages, and, ultimately, nearshore marine waters.

Watershed Characterization

Unless noted, the following summary is taken from *Thurston County Geodata Center (2007*).

Henderson Inlet watershed covers 40 square miles east of Olympia, Washington (Figure 1). Its axis runs 12.5 miles south-southwest from Johnson Point to its southern border (between Long and Pattison Lakes). Four sub basins drain into Henderson Inlet.

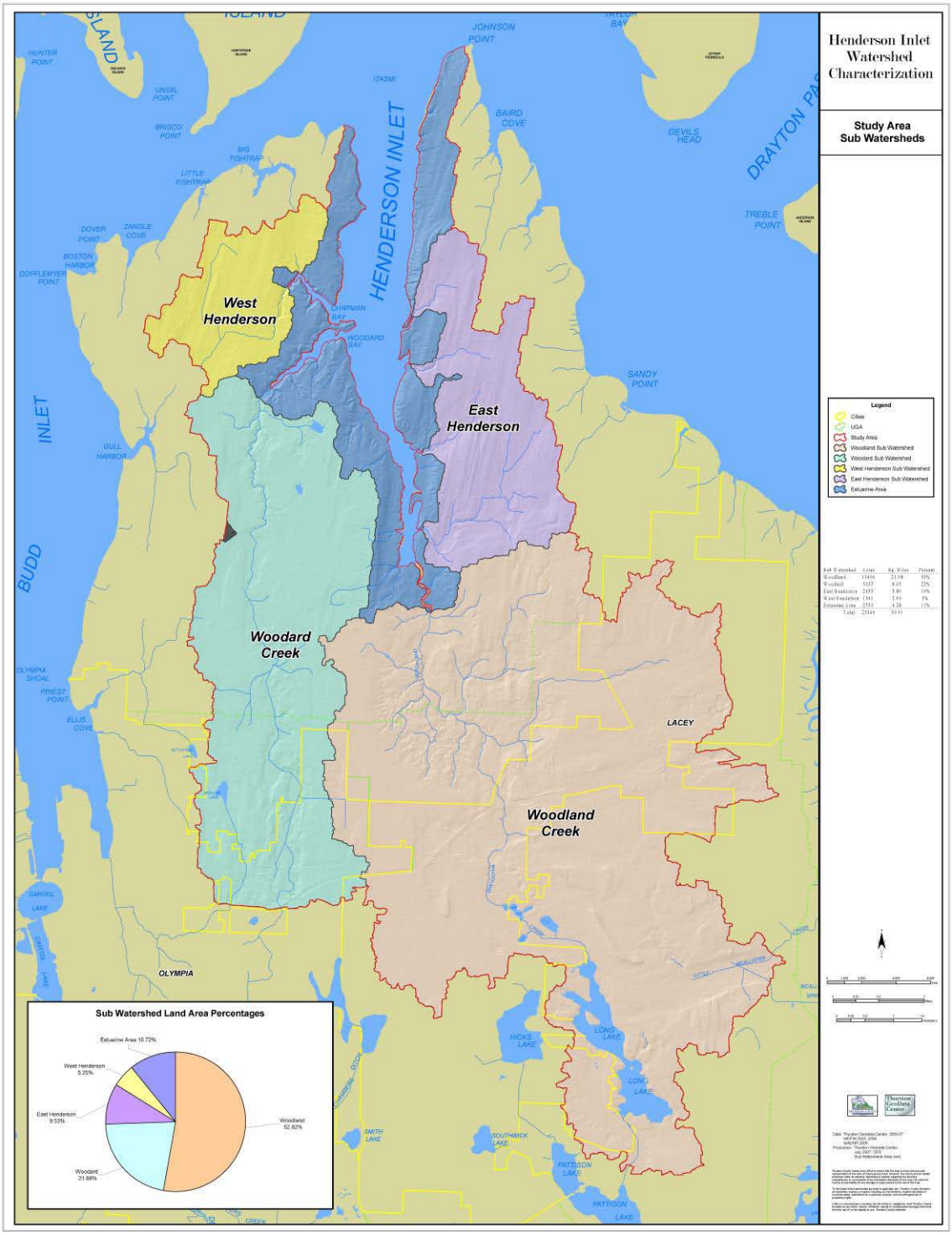
Woodland Creek sub basin covers just over half the watershed. Woodland Creek discharges into the southern end of the Inlet. 90% of Woodland Creek sub basin lies within the urban growth area of Lacey and Olympia. Urban development associated with the cities of Lacey and Olympia is connected to a sewage treatment system (WDOH 2007). Woodland Creek is dominated by residential suburbs, particularly in the southern lakes area.

Woodard Creek sub basin covers the southwestern quarter of the watershed. Woodland Creek discharges into Woodard Bay on the west-central shore of Henderson Inlet. Woodard Creek arises in wetlands surrounded by high-density commercial activity. 16% of Woodard Creek sustains urban uses. The southernmost portion, mainly Olympia, supports residential uses.

West Henderson and East Henderson sub basins occupy the northern end of the watershed (15% of total or 6.1 square miles). Several small streams discharge from these sub basins. The primary land activities are rural, residential, and agricultural. The area immediately surrounding Henderson Inlet covers four square miles. The shoreline is 17.5 miles long. WDOH (2007) identified 78 different drainage/discharge points, 253 developed parcels and 24 agricultural activities along the marine shoreline. 22% of parcels were served with on-site sewage systems that posed a risk to shellfish resources (although none posed a threat at the time of the survey).

Henderson Inlet is about five miles long, and averages a half-mile wide. A large part of the Inlet (particularly the southern end) is exposed during low tides. Twelve tribal and non-tribal shellfish growers (including the Henderson Inlet Community Shellfish Farm, sponsored by the Puget Sound Restoration Fund) harvest oysters, hard-shell clams, and geoducks from 2.5 square miles of shellfish beds (WDOH database, 2011).

Figure 1. Delineation of boundaries of subwatersheds in Henderson Inlet (Thurston County GeoData Center, Water and Waste Management, 2007)



Remedial Action Summary

Major potential pollution sources in Henderson Inlet sources include failed onsite sewage systems, farm animal waste, and contaminated urban stormwater. The county has carried out outreach and remedial programs for over two decades, although there has been greater focus during the most recent decade. In late 2001, Thurston County created a Shellfish Protection District for Henderson Inlet. Creation of the District enabled the County to generate a Shellfish Protection Fund. The fund assists local agencies carry out remedial programs.

Thurston County Health Department (TCHD). For several decades TCHD has inspected onsite sewage systems along the shores of Henderson Inlet and upland drainages. In November 2005, the County adopted a Septic System Operation and Maintenance Program. The program covers more than 6000 onsite sewage systems in the Watershed. Later, TCHD set up the Henderson Septic Owner Certification Training Program, which has trained over 1800 homeowners to inspect and maintain their own systems. The Health Department also provides financial aid to low -income, elderly, or disabled residents for repair and maintenance of their systems through the Small Works Septic Grant Program. The Thurston County Board of Health is expected to issue a public-health order requiring connection to the sanitary sewer system for 128 homes in the Woodland Creek Estates and Covington Place.

Thurston Conservation District. The Thurston Conservation District (CD) estimated a total of 156 farms in Henderson Inlet, 17 of which had farm plans (*Henderson Windshield Surveys 4/17*, Thurston CD, 2006). Less than 1% of the agricultural land is cropland (Kathleen Whalen, Administrator, Thurston Conservation District, personal communication). The Thurston Conservation District (CD) receives 28% of SPF funds each year for work in the Henderson watershed. The work includes outreach and technical assistance to rural landowners. The CD helps rural landowners protect and preserve the productivity of their land and natural resources downstream (including fish and shellfish). To this end, the CD helps rural landowners design and implement “conservation plans”. A conservation plan is a list of best management practices (BMPs) selected for each site that controls the export of contaminated runoff from the farm. BMPs may include synchronized grazing, manure management, exclusion of animals from streams, buffer strips, runoff control, and waste storage/transfer systems. From 2000-2002, BMPs were installed on 327 acres. In 2005, the CD provided technical assistance to 27 farms. That year, the CD helped install 15 BMPs, and 5 conservation plans were developed. The CD also arranges cost-share for qualified landowners. Since 2005, the SPF has funded 2-6 cost-share projects a year. Thurston CD has grant funding from the Department of Ecology to continue farm planning and implementation of BMPs aimed at improving water quality on high priority streams within the watershed. These grants run through 2012.

Other Activities. Both cities of Lacey and Olympia havestormwater utilities that ensure installation and maintenance of stormwater systems. The City of Olympia Wastewater Utility established a “Septic to Sewer Program” in 2009. The voluntary program provides incentives to homeowners with septic systems to connect to public sewer.

Henderson Inlet Community Shellfish Farm. The Community Shellfish Farm started in 2003 on tidelands owned by WSU. The Shellfish Farm is funded by the Puget Sound Restoration Fund. The Shellfish Farm educates students, watershed residents, and political leaders about in shellfish culture and water quality. Henderson Inlet Community Shellfish Farm provided education in shellfish culture and water quality in partnership with South sound Green. In 2006 nearly 1000 students visited the Farm. In 2008 the Henderson Inlet Community Shellfish Farm established 24 shellfish gardens on private tidelands to invest waterfront landowners in water quality.

Status and Trend of Fecal Pollution in Henderson Inlet

Classification of Henderson Inlet. DOH uses guidance from the National Shellfish Sanitation Program to classify shellfish growing areas (NSSP 2009). The Department has sampled Henderson Inlet monthly for fecal coliform (FC) bacteria for nearly two decades. Twenty-four stations have been sampled continuously. Six additional sites were added over the period.

DOH calculates statistics (geometric means and estimated 90th percentiles) for each station using FC results from a minimum of 30 prior sampling dates, as required by NSSP (2009). DOH uses the statistics to classify Henderson Inlet for shellfish harvest. (Appendix C, "Shellfish Growing Area Classification", WDOH 2010). Currently most of outer Henderson Inlet is classified as Approved. The innermost southern end (fed by Woodland Creek) is either Conditionally Approved or Prohibited. Woodard Bay (fed by Woodard Creek) is Prohibited. (Figure 1).

Status and Trends in Fecal Pollution. Since 1998, DOH used fecal coliform data from the 24 continuously monitored sites to evaluate the status and trend in fecal pollution for all Henderson Inlet (Approved, Conditionally Approved, and Prohibited). Results were reported to the Puget Sound Assessment and Monitoring Program (PSAMP). The most recent PSAMP report was WDOH (2010).

The Fecal Pollution Index. DOH developed a 'fecal pollution index" or FPI as a simple unitless measure of fecal pollution impact. Its derivation and use are described in full in Appendix B, WDOH (2010). In brief, each year's 90th percentiles from all stations and all sampling dates are sorted into categories of "GOOD" (90th percentiles $\leq$ 30 MPN/100ml), "FAIR" (30 < FPI $\leq$ 43 MPN/100ml), and "BAD" (> 43 MPN/100ml). The FPI is derived from the weighted proportions of 90th percentiles in each category. Simply stated, the annual FPI may range from 1.0 (100% GOOD 90th percentiles) to 3.0 (100% BAD 90th percentiles).

Figure 2 shows trend in fecal pollution throughout all of Henderson Inlet using the annual FPI. Fecal pollution impact is defined in terms of FPI, as follows: "Negligible": FPI = 1.0, "Low": 1.00 > FPI $\leq$ 1.50, "Moderate": 1.50 > FPI $\leq$ 2.00, "High": 2.00 > FPI $\leq$ 2.50, and "Very High": 2.50 > FPI $\leq$ 3.00. A Runs Test for trends (Sokal and Rohlf 1969) suggests that fecal pollution has been reduced significantly over the last decade (t_s = -2.35, p = 0.05). The annual FPI dropped from an FPI of 2.1 ("High" fecal pollution impact) in 2001 to 1.2 ("Low" fecal pollution impact) in 2009.

Figure 2. Sampling sites in Henderson Inlet, including those specifically selected for analysis of trends and correlations between fecal pollution and rainfall characteristics.

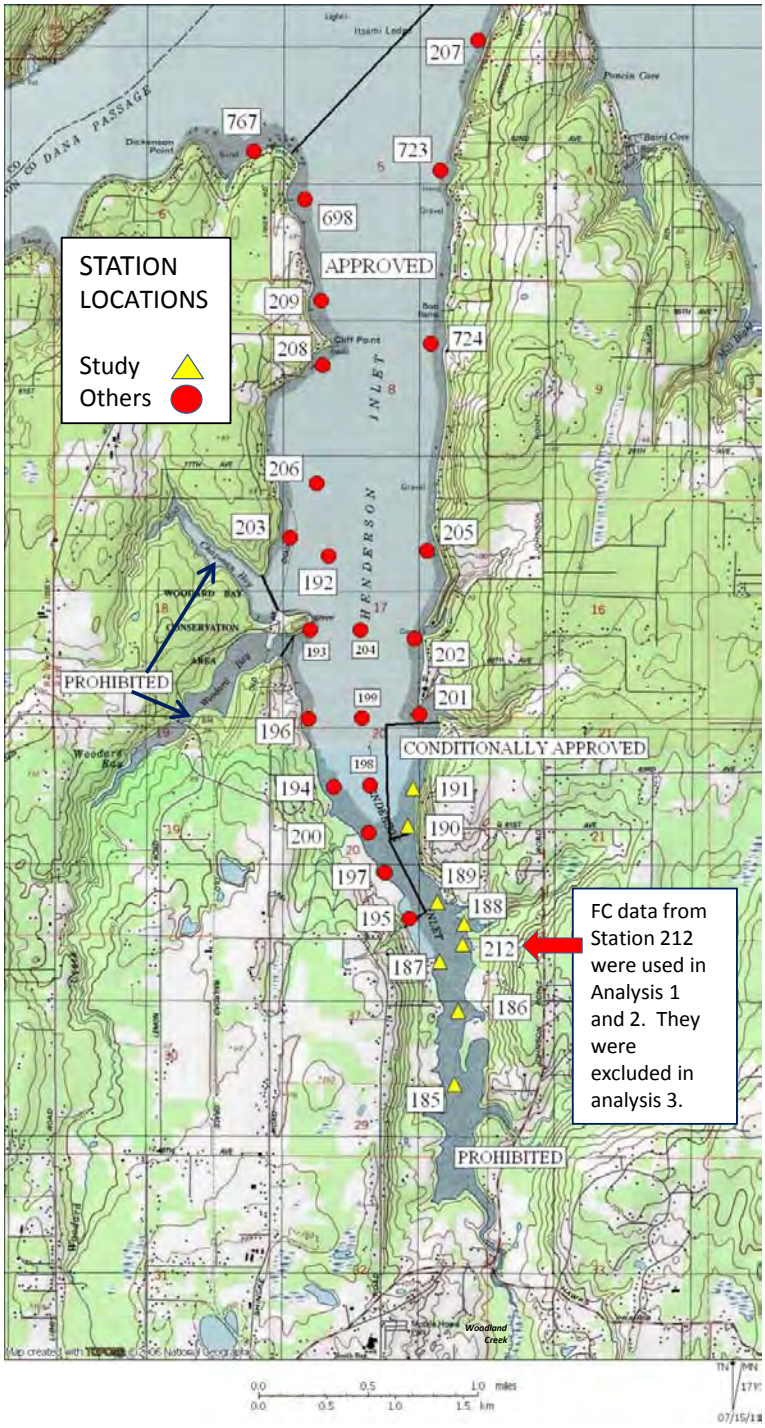
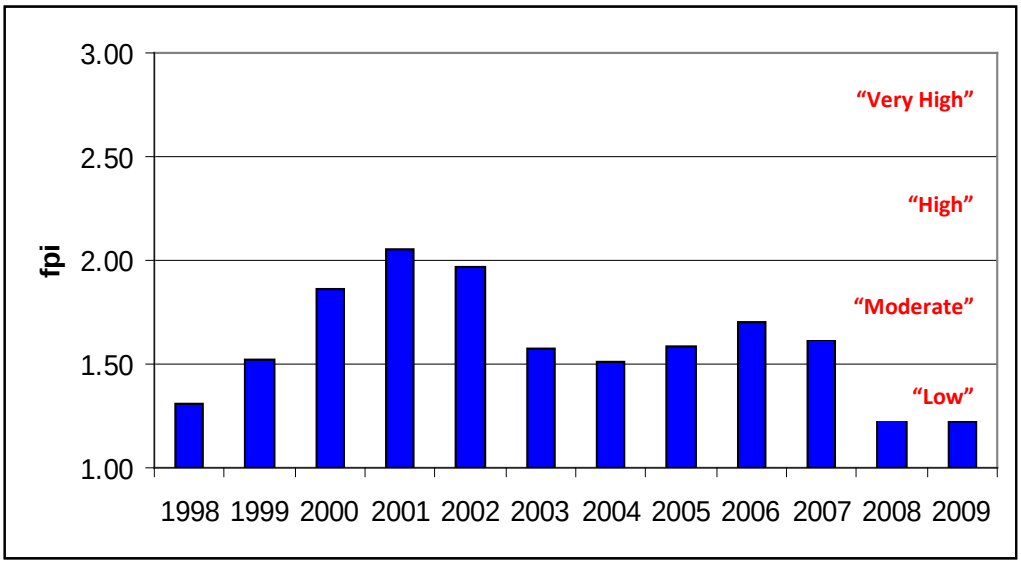


Figure 3. Trend in fecal pollution in Henderson Inlet (from WDOH 2010). The fecal pollution indices (FPIs) were calculated from results obtained from 24 continuously monitored sites throughout Henderson Inlet. (FPI = 1.0: "Negligible" impact)



Methods

Study Area. Eight DOH sampling stations (stations 185-191, 212; Figure 1) in the southern end of Henderson were identified for more detailed analysis of changes in fecal pollution and their relationship to rainfall. These stations are subject to direct influence from Woodland Creek. The area is also subject to minimum tidal exchange. The stations lie within regions of Henderson Inlet that are classified either Prohibited and Conditionally Approved .

I did not include the Woodard Creek sub basin in this analysis. Although Woodard Creek likely contributes significant fecal contamination to Henderson Inlet, there are no sampling stations that are exclusively affected by watershed pollution sources. There is reason to believe that Station 193 (located outside of Woodard Bay, see Figure 1) may be affected by seals hauled out on log booms located to the north of the station.

Rainfall Data. Daily rainfall data used to evaluate fecal pollution in Henderson Inlet are collected at the Olympia Airport located about 11 miles south of Henderson Inlet Watershed.

Analytical Approaches

I used three independent analytical approaches in the study.

Analysis 1. Annualized Fecal Coliform Statistics and Total Annual Rainfall. I pooled individual fecal coliform results from the 8 stations for each year from 2000 through 2009. Annual statistics (geometric means and 90th percentiles) were calculated ($n \approx 84$; i.e., 7 stations sampled roughly 12 times each year). These statistics were aligned with total annual rainfall for each year and analyzed for temporal trend and correlations.

Analysis 2. Fecal Coliform Statistics by Sampling Date and "Recent" Rainfall Parameters. Fecal coliform results from the 8 stations (stations 185-191, and 212) were pooled for each sampling date from 2000 through 2009. Geometric means and 90th percentiles were calculated from the pooled data for each date. These statistics were aligned with "recent" rainfall parameters derived for each sampling date. For the present analysis, I assumed "recent" to mean a 5-day limit, beyond which the effect of the initial daily rainfall would likely be undetectable.

The "recent" rainfall parameters were:

1. 24-hour rainfall ("$Rain_{1\text{-}day}$"),
2. total rainfall from the previous 5 days ($Rain_{5\text{-}day}$), and
3. 5-day Antecedent Precipitation Index ($API_{5\text{-}day}$).

The "antecedent precipitation index" (or API) is used by hydrologists and engineers as a measure of the effect of elapsed time on the flow of runoff (e.g., Rao, et al 1978, Dunne and Leopold 1978).

$$API_{5\text{-}day} = P_{day1} + 1/P_{day2} + 1/P_{day3} + 1/P_{day4} + 1/P_{day5}$$

where P_{dayx} = Precipitation on day_x

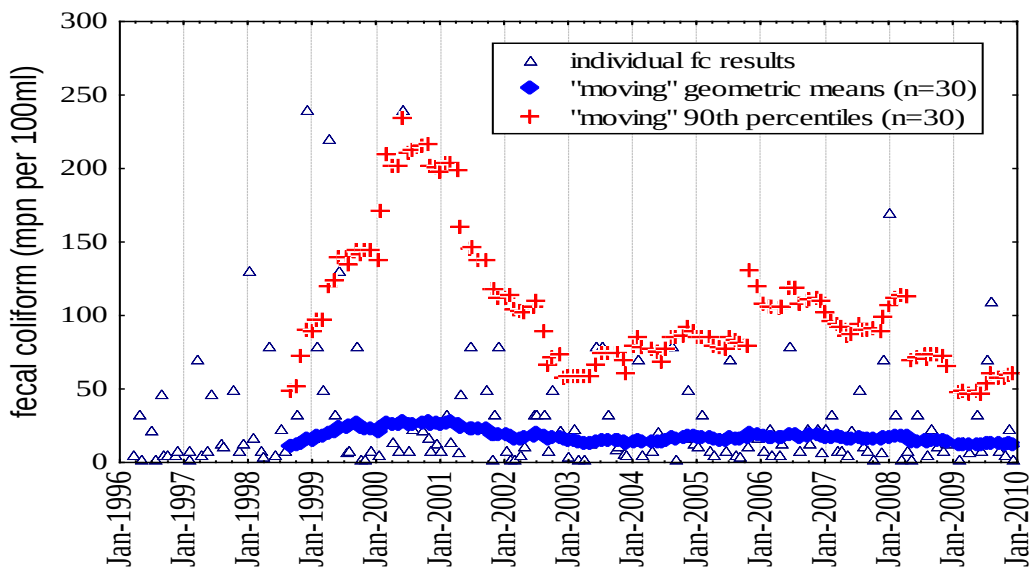
Analysis 3. "Moving" Statistics for Both Fecal Pollution and Daily Rainfall (Adapting NSSP Protocols). Analysis 3 was designed to provide the best possible fit between FC results and the daily rainfall data. I calculated moving statistics (geometric means, medians, and 90th percentiles) for both FC and daily rainfall for each sampling date. The calculations followed the protocol mandated by the National Shellfish Sanitation Program (NSSP) (see NSSP 2009 and Appendix A, WDOH 2010.

Both fecal coliform and rainfall data tend to be highly variable and skewed over time. The statistics control the effect of skewness (http://en.wikipedia.org/wiki/Skewness). NSSP requires a high minimum number of data for calculations (n=30), which controls the effect of variability. The large dataset (n = 30) has the advantage of emphasizing longer term trends and patterns (see http://en.wikipedia.org/wiki/Moving_average). When calculated for all sampling dates and plotted

against time, the statistics produce a moving analytical time frame that can show a trend with time.

Fecal Pollution Data. Figure 3 shows the three fecal pollution parameters (individual results, and geometric means and 90th percentiles calculated from individual results) plotted against time at Station 186 (find location in Figure 1).

Figure 4. Trend in fecal pollution at Station 186 showing 3 fecal coliform parameters.



The NSSP procedure is typically applied at the level of the sampling station. However, for Analysis 3, I pooled results from seven innermost stations (185-191) for each sampling date, and calculated a geometric mean from the pooled results. This provided a single representative value for the innermost part of Henderson Inlet. I then substituted the geometric means in the NSSP procedure instead of individual fecal coliform results. (Note: data from Station 212 were excluded from Analysis 3 because the data record was shorter than those of the other stations by several years.)

Rainfall Data. As described earlier, I calculated moving statistics (geometric means, medians, and 90th percentiles) for daily rainfall using the NSSP-mandated number of prior data (n = 30). Many sampling days had no rainfall. To deal with "zero-rain" days, I added the value 1.0 to each daily rainfall value before calculating of the statistics. Thus, zeros are eliminated from the data, although the data retain the same relationship relative to one another (the "log (x+1) transformation; Sokal and Rohlf 1969).

Analytical Tools. *Statistica* (Statsoft 6.1) was used to perform the Spearman's rank correlation coefficient (rho) test relationships between ranked variables of fecal pollution and time

(http://en.wikipedia.org/wiki/Spearman's_rank_correlation_coefficient, http://geographyfieldwork.com/SpearmansRank.htm). Rho ranges from -1.0 (perfect negative relationship) to +1.0 (perfect positive relationship). Rho = 0.0 means there is no relationship.

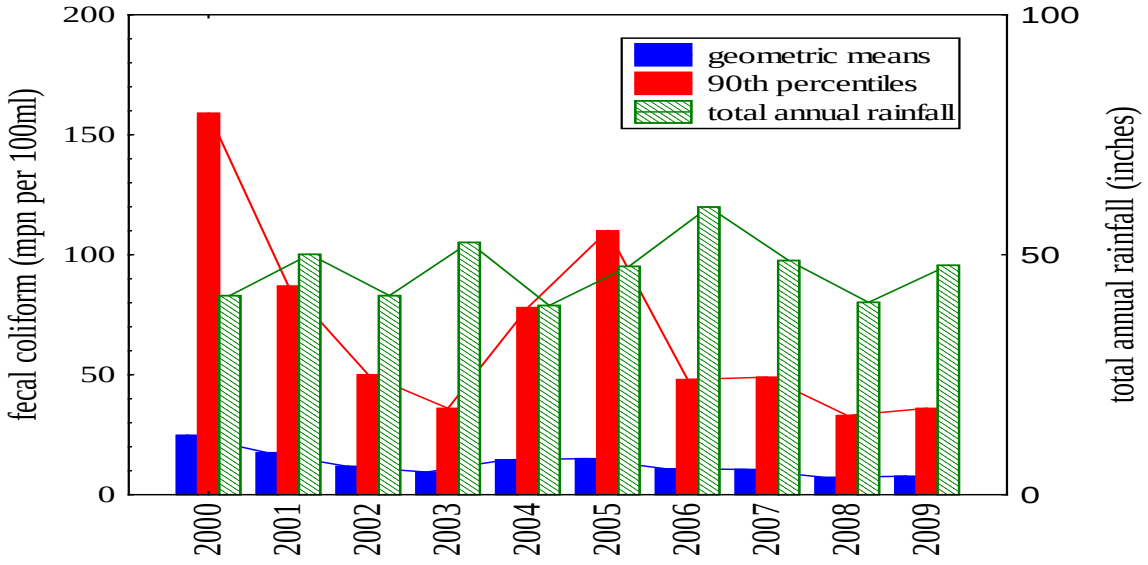
Results and Discussion

Analysis 1. Annualized Fecal Coliform Statistics and Total Annual Rainfall. Table 1 summarizes the results of statistical tests. The results in Table 1 suggest that annualized FC statistics (geometric means and 90th percentiles) declined significantly over time (Tests 1, 2). However, total annual rainfall (Test 3) showed no significant temporal trend. Nor did FC statistics correlate significantly with total annual rainfall (Tests 4 and 5). Figure 4 shows annualized FC statistics and total annual rainfall over time from inner Henderson Bay.

Table 1. Summary of statistical tests (Spearman's correlation strength, Rho) of annualized fecal coliform statistics and total annual rainfall from 8 stations in inner Henderson Bay.

Tests	N	Rho	p-level	Conclusion
(1) $FC_{geometric}$ & YEAR	10	-0.794	≤0.05	declining
(2) FC_{90th} & YEAR	10	-0.699	≤0.05	declining
(3) $Rain_{annual}$ & YEAR	10	0.030	≥0.05	no trend
(4) $FC_{geometric}$ & $Rain_{annual}$	10	-0.103	≥0.05	no correl
(5) FC_{90th} & $Rain_{annual}$	10	-0.195	≥0.05	no correl

Figure 5. Trend in annualized fecal pollution statistics and total annual rainfall from eight stations in inner Henderson Inlet.



Analysis 2. Fecal Coliform Statistics by Sampling Date and "Recent" Rainfall. Table 2 summarizes the results of statistical tests for the second analysis. Geometric means and 90th percentiles of fecal coliform data (Tests 1 and 2) show a significant decline over time (see Figure 5). "Recent" rainfall parameters (Tests 3-5) show no temporal trend. There appears to be no significant relationship between FC statistics and rainfall (tests 6-11). This outcome is likely due to highly variable "recent" rainfall parameters (see Figure 6).

Table 2. Summary of statistical tests (Spearman's correlation strength, Rho) of fecal coliform statistics vs. rainfall statistics from 8 stations in inner Henderson Bay paired by sampling date.

Tests	N	Rho	p-level	Conclusion
1) $FC_{geomean}$ vs Date	119	-0.275	≤0.05	decreasing
2) $FC_{90th\ percentile}$ vs. Date	119	-0.262	≤0.05	decreasing
3) $Rain_{1\text{-}day}$ & Date	119	0.013	≥0.05	no trend
4) $Rain_{5\text{-}Day}$ vs Date	119	0.019	≥0.05	no trend
5) $API_{3\text{-}day}$ & Date	119	-0.035	≥0.05	no trend
6) $FC_{geomean}$ & $Rain_{1\text{-}day}$	119	0.157	≥0.05	no correlation
7) $FC_{geomean}$ & $Rain_{5\text{-}Day}$	119	0.095	≥0.05	no correlation
8) $FC_{geomean}$ & $API_{3\text{-}day}$	119	0.151	≥0.05	no correlation
9) $FC_{90th\ percentile}$ & $Rain_{1\text{-}day}$	119	0.174	≥0.05	no correlation
10) $FC_{90th\ percentile}$ & $Rain_{5\text{-}Day}$	119	0.095	≥0.05	no correlation
11) $FC_{90th\ percentile}$ & $API_{3\text{-}day}$	119	0.172	≥0.05	no correlation

Figure 6. Trend in fecal pollution statistics for eight stations in inner Henderson Inlet (Analysis 2).

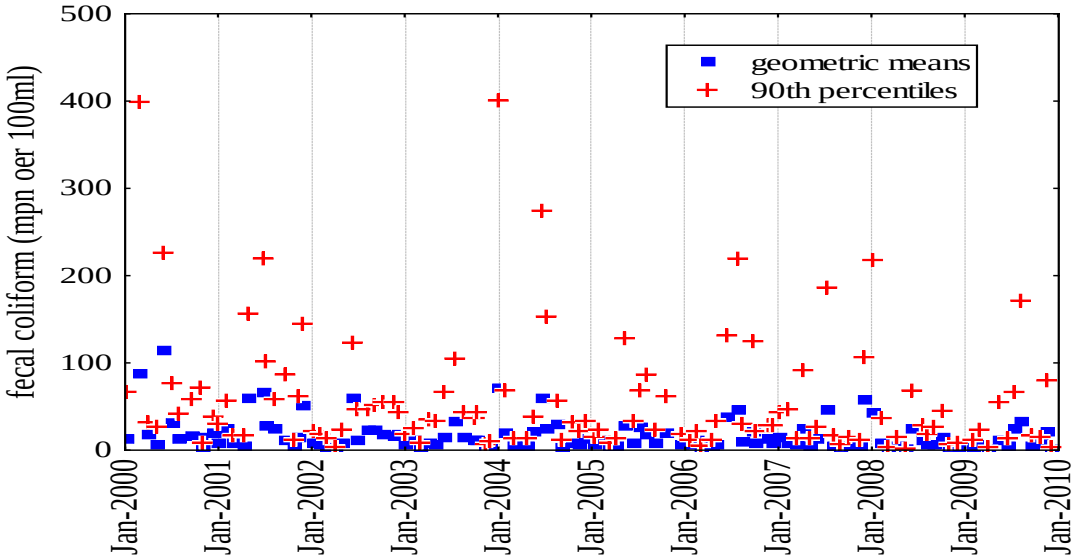
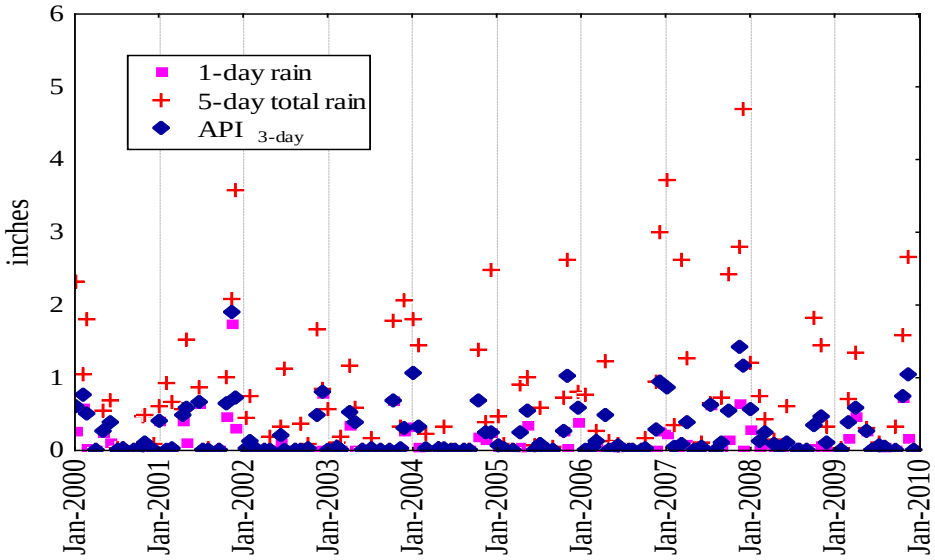


Figure 7. Trend in "Recent" Rainfall in Henderson Inlet (data from Olympia Airport) "API" means"antecedent precipitation index (see page 9).



Analysis 3. "Moving" Statistics for Fecal Coliforms and Daily Rainfall by Sampling Date.
Table 3 shows the results of statistical tests using the NSSP-based approach. Fecal pollution statistics significantly declined over time in the innermost seven stations of Henderson Inlet (tests 1 and 2, Figure 7). There is also evidence of reduced rainfall with time (tests 3-5, Figure 8). However, the relatively low Rho values (-0.235, -0.304, and -0.257, respectively) suggest the link is not strong. On the other hand, Figure 8 suggests that rainfall increased markedly in 2009. Despite the increase fecal pollution statistics did not appear to increase in response to the increased rainfall. In order to explore this idea more closely, I combined the two most sensitive statistics (90th percentiles of FC and daily rainfall). Figure 9 explores this idea in detail. The pattern may suggest that control of fecal pollution has reduced the potential for contamination of runoff flowing into Henderson Inlet.

Table 3. Summary of statistical tests (Spearman's correlation strength, Rho) of 'moving" fecal coliform statistics vs. moving rainfall statistics from eight stations in inner Henderson Inlet. Fecal coliform and rainfall statistics (geomeans, medians, and 90% percentiles) were calculated from n = 30 values (NSSP protocol).

Tests	N	Rho	p-level	Conclusion
1) FC_{geom} vs. Date	115	-0.837	≤0.05	declining
2) $FC_{90th\text{-}percentiles}$ vs. Date	115	-0.632	≤0.05	declining
3) $Rain_{medians(x+1)}$ vs. Date	115	-0.235	≤0.05	declining
4) $Rain_{geom(x+1)}$ vs Date	115	-0.304	≤0.05	declining
5) $Rain_{90th\text{-}percentiles(x+1)}$ vs Date	115	-0.257	≤0.05	declining
6) FC_{geom} vs. $Rain_{medians(x+1)}$	115	0.032	≥0.05	no correlation
7) $FC_{90th\text{-}percentiles}$ vs. $Rain_{medians(x+1)}$	115	0.327	≤0.05	correlation
8) FC_{geom} vs. $RAIN_{geom(x+1)}$	115	0.243	≤0.05	correlation
9) $FC_{90th\text{-}percentiles}$ vs. $RAIN_{geom(x+1)}$	115	-0.020	≥0.05	no correlation
10) FC_{geom} vs. $Rain_{90th\text{-}percentiles(x+1)}$	115	0.168	≥0.05	no correlation
11) $FC_{90th\text{-}percentiles}$ vs. $Rain_{90th\text{-}percentiles(x+1)}$	115	-0.128	≥0.05	no correlation

Figure 8. Trend in fecal pollution in inner Henderson Inlet (based on the NSSP procedure). (The sharp increase in fecal pollution in late 2005 was likely due to a series of severe rain storms coinciding with sampling dates.)

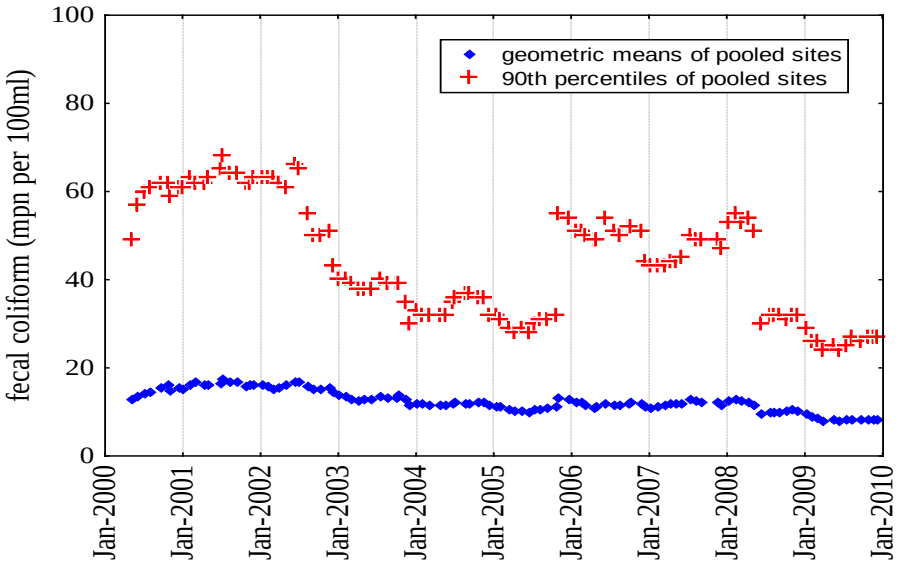
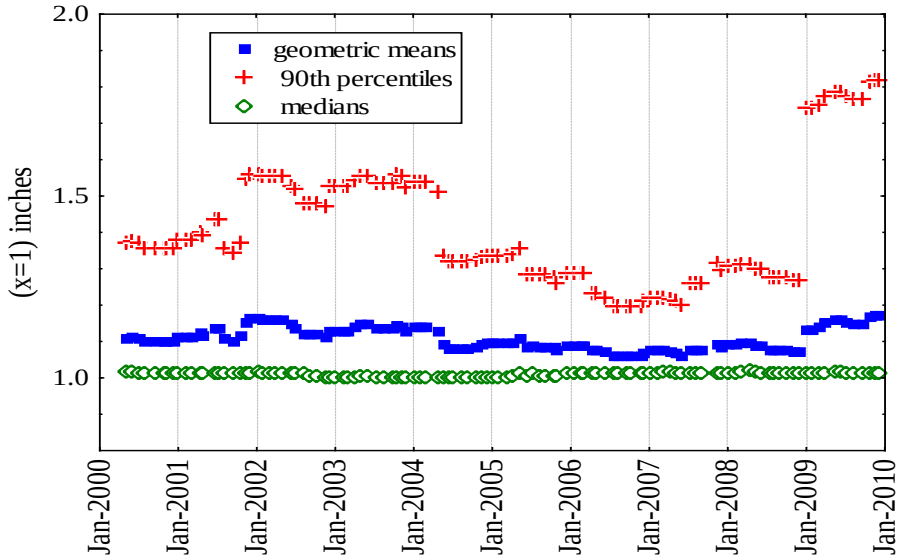
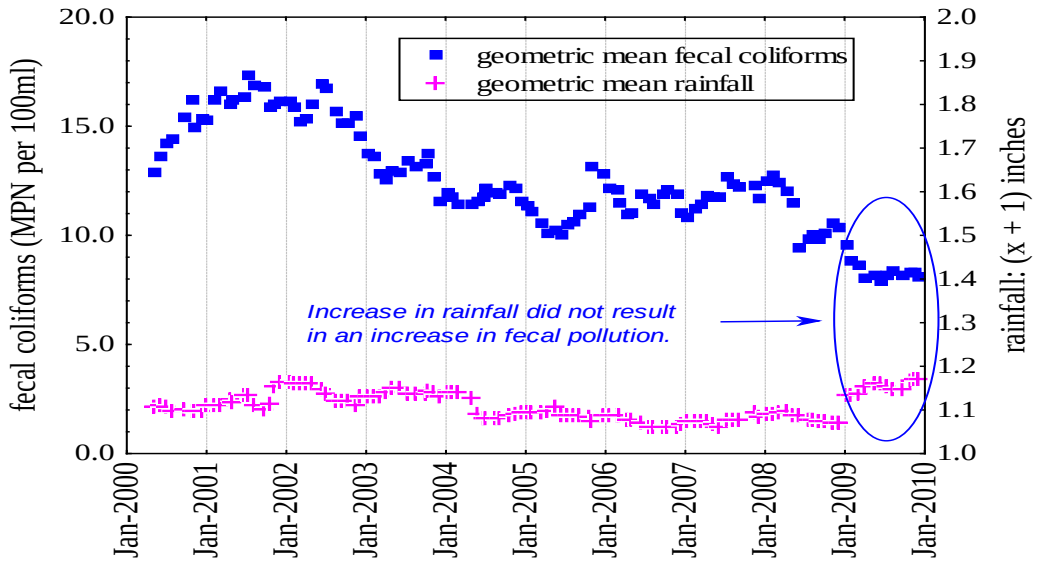


Figure 9. Trend in moving rainfall statistics calculated according to NSSP procedure.



The third approach also demonstrates a significant positive relationship between geometric mean fecal pollution and median rainfall (test 5, Figure 9). However, the very low Spearman coefficients in Test 5 suggest the relationship is weak. Other fecal pollution and rainfall statistics (tests 6-8) showed no relationship.

Figure 10. Trend in ninetieth percentiles of fecal coliforms and daily rainfall from 2000 through 2009



.

Conclusions

- All three analytical approaches used for this analysis show that fecal pollution has significantly decreased over the last decade in the innermost end of Henderson Inlet.
- The first two analytical approaches show no detectable change in rainfall over the past decade. However, the third NSSP-based approach suggested that rainfall may have declined during the past decade, but the effect appears to be small.
- Despite evidence of increased rainfall in 2009 (Approach 3), fecal pollution has not increased. Thus remedial action to date may have been effective in controlling export of fecal pollution from the Henderson Inlet watershed.
- The first two approaches show no relationship between fecal pollution and rainfall. However, the third approach suggests a slight (if subtle) link between reduced fecal pollution and diminished rainfall.
- The third analytical approach appears to be the most powerful of the three tools when exploring temporal trend of rainfall and relationships between fecal pollution and rainfall.

In summary, fecal pollution has dropped significantly in the south end of Henderson Inlet. Although reduced precipitation may have played a small role in the reduction, it does not explain the degree of the fecal pollution reduction. By inference, remedial action was likely the greater factor in the reduction of fecal pollution in Henderson Inlet.

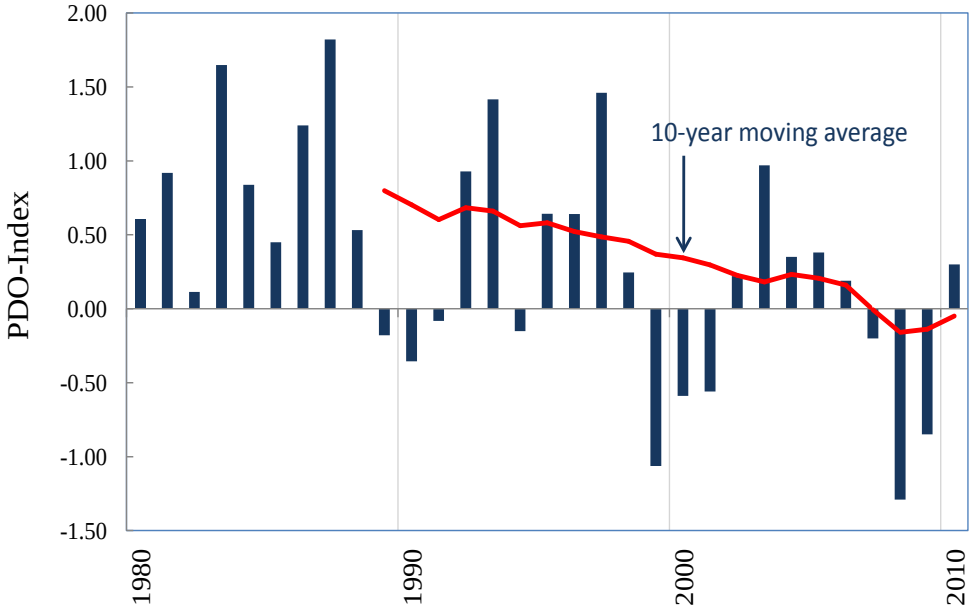
Future Challenges

Increased Population and Development. Between 1985 and 2000, urban cover in Henderson Inlet increased by 31%, and 12% of rural land was converted to urban uses (Thurston Regional Planning Council 2009). Through 2009 fecal pollution in Henderson Inlet has been reduced despite relentless urban expansion. However, by 2030, population in Henderson Inlet will likely increase by 28% to over 85, 000 people, and urban cover (measured as total impervious surface) is projected to increase by 24% (Thurston Regional Planning Council 2009).

Long-term Climate Fluctuations. The present study is limited in temporal and spatial scale. The broader question remains: what is the effect of long-term climatic fluctuations on fecal pollution in Puget Sound? Mantua, et al (1997) explored how fluctuating climate patterns affected salmon populations in the Pacific Northwest and Alaska. The authors used (among other tools) the "Pacific (inter) Decadal Oscillation" (PDO), a pattern of climatic fluctuation in the North Pacific Ocean. A PDO-Index is derived, in part, from sea surface temperature data. Mantua, et al (1997) used the PDO-Index to identify several climate reversals during the previous century: mostly positive PDO from 1925 through 1946, negative PDO between 1947 and 1976, and positive PDO from 1977 through 1997. During periods of positive PDO, the climate in Washington and Canada tends toward lighter than normal rainfall. Flows from three major Pacific Northwest rivers (Skeena, Fraser, and Columbia) are also markedly lower.

Figure 11 shows annual average PDO-Indices from 1980 through 2010. I obtained a table of monthly PDO-Index values from the Joint Institute for the Study of the Atmosphere and Oceans (JISAO), University of Washington (http://jisao.washington.edu/pdo/PDO.latest). The monthly values were averaged to produce annual PDO-Indices (Christopher Krembs, personal communication). The 10-year moving average is used to illustrate significant changes (Krembs, personal communication). The post-1977 positive PDO signature noted by Mantua, et al (1997) is evident. However, the moving average suggests that a negative signature may be developing. The shift could lead to heavier, more frequent rainfall and increased runoff. Pressure on pollution control programs will likely intensify.

Figure 11. Annual average PDO-Indices from 1980 through 2010.



Implications

- In the face of increased population and urban density in Henderson inlet, local remedial programs must not only be maintained, but intensified if shellfish harvest is to continue during the coming decades.
- The climate may be drifting toward heavier, more frequent rainfall and increased runoff. Pressure on pollution control programs will likely intensify.
- Each watershed citizen, whether a large landholder or homeowner, must develop a strong personal ethic toward stewardship of their property. The role of government, through either regulation or incentive, will likely not be able to keep up with the cost of watershed management.
- Henderson Inlet, due to the importance of its shellfish resources and the increasing urbanization of its watershed, may serve as a powerful natural experiment to estimate how intensively a watershed can develop and still sustain a harvestable shellfish resource.

References

Dunne, Thomas and Luna B. Leopold (1978). Water in Environmental Planning. W.H. Freeman and Co. NY.

National Climatic Data Center, U.S. Department of Commerce. http://www.ncdc.noaa.gov/oa/climate/research/cag3/wa.html .

NSSP (2009). The National Shellfish Sanitation Program Guide to the Control of Mulluscan Shellfish. http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FederalStatePrograms/NationalShellfishSanitationProgram/ucm046353.htm

Rao, T. B., G. Ranganna, and I. V. Nayak (1978). How Much Precipitation Goes Into Infiltration during a Storm Period? Nordic Hydrology 6: 93-113. http://www.iwaponline.com/nh/006/0093/0060093.pdf

Sokal, Robert R. and F. James Rohlf (1969). Biometry: the principles and practice of statistics in biological research. W.H. Freeman and Co., San Francisco, California. 776 pp.

StatSoft, Inc. (1997). STATISTICA 6.1, www.statsoft.com., Tulsa, OK.

Thurston County GeoData Center Water and Waste Management (2007) Henderson Inlet Watershed Characterization Report**.** Water and Waste Management. Olympia, WA**.** 120 pages. http://www.co.thurston.wa.us/stormwater/chara/chara-henderson.html

http://cliffmass.blogspot.com/2011/10/is-west-coast-weather-getting-more.html

Thurston Regional Plannning Council (2010). The Profile. Olympia WA. 332 pp. http://trpc.org/data/Pages/profile.aspx

Washington State Department of Health (2007). Sanitary Survey of Henderson Inlet. Office of Shellfish and Water Protection. Olympia WA. 42 pp.

Washington State Department of Health (2010). Status and Trends in Fecal Coliform Pollution in Shellfish Growing Areas of Puget Sound: Year 2009. Office of Food Safety and Shellfish Programs. Olympia WA 151 pp. http://www.doh.wa.gov/ehp/sf/Pubs/fecalreport.pdf.