PNWD-4054-3

Effectiveness Monitoring of Fecal Coliform Bacteria and Nutrients in the Dungeness Watershed, Washington

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Prepared for:
Jamestown S'Klallam tribe
in fulfillment of Task 3 (Effectiveness Monitoring Study)
of the Dungeness River Watershed Final Workplan
for the EPA Targeted Watershed Grant Program (2004)

October 2009

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Executive Summary

This study was conducted as part of an Environmental Protection Agency Targeted Watershed Grant awarded to the Jamestown S'Klallam Tribe in 2004 that focused surface water cleanup efforts in the lower Dungeness Watershed and Dungeness Bay in Washington State. The Targeted Watershed Grant (TWG) program contained a number of elements that utilized innovative community-based approaches and management techniques to promote and restore clean surface waters, including:

- *Task 1* A microbial source tracking study to determine the predominant sources of fecal coliform bacteria in the lower watershed and Bay (Woodruff et al. 2009).

- *Task 2* Innovative best management practice (BMP) demonstrations including a Mycoremediation Demonstration for the removal of fecal coliform and nutrients (Thomas et al. 2009), homeowner sewage management education and training (including cost-share incentives for septic repairs) and an irrigation ditch piping demonstration.

- *Task 3* An effectiveness monitoring study that evaluated the effectiveness of the best management practices conducted in *Task 2*, and examined the implications within a larger watershed context both geographically and temporally.

- *Task 4* A public outreach component to better inform the public about bacterial pollution, prevention, and remediation activities, and to provide regular updates on project findings.

This report presents the results of *Task 3*, the Effectiveness Monitoring Study, which includes the following components:

- A statistical examination of fecal coliform trends in the Dungeness watershed and Dungeness Bay over the past decade, including data collected as part of the TWG study (2005 through 2008).

- A characterization of the nutrients in the watershed, collected as part of the TWG study.

- A statistical evaluation of the effectiveness of BMPs from *Task 2* (i.e. irrigation piping and septic system repairs) for remediating fecal coliform bacteria. The mycoremediation BMP effectiveness is discussed in a separate report (Thomas et al. 2009)

The overall results of this study have not shown an improvement in surface water quality with respect to fecal coliform bacteria in the Dungeness watershed or Dungeness Bay within the last 10 years. However, water quality conditions have not declined within the watershed either. This is notable when considering the population within the Dungeness watershed has steadily increased during this time period. Population pressures have resulted in greater use of onsite sewage treatment systems and a shift in land use including an increase of impervious surfaces, which has likely imposed additional pressures on the watershed and Bay. The observed "steady state" condition of water quality may be due in some part to BMP measures that have been implemented as a result of urban and rural development in the watershed. Additionally, local education and outreach programs have focused on ways to mitigate for bacterial contamination resulting in an increased awareness and responsiveness within the local community.

Fecal Coliform Trends

Freshwater fecal coliform (FC) data from more than 2000 samples collected between 1998 and 2008 were analyzed for trends over time and by geographic area. The samples were collected from over 55 stations along the Dungeness River, its tributaries, nearby creeks and irrigation ditches. The samples collected during this time period had natural high variability with respect to concentration, sometimes differing by several orders of magnitude. In order to examine the possible sources of variability within the data, regression models were used to partition potential sources (tributary, month, season, and year) that could be linked to the variation. Based on these models, there was no significant increase or decrease in the annual mean FC concentration during the time period examined. The year 2000 had the highest geometric mean concentration. There was a distinct seasonal pattern noted, with the dry season (April through September) having significantly higher FC concentration than the wet season (October through March). There was also a decrease in FC concentration with increasing distance from the mouth of the river or any given tributary or creek. The Dungeness River had the lowest median concentration of bacteria of all freshwater bodies examined (i.e. Dungeness River, Matriotti Creek, Meadowbrook Creek, Meadowbrook Slough, Bell Creek, and Johnson creek), ranging between 2 and 12 CFU/100 ml. Of the Dungeness tributaries, Matriotti Creek had the highest median concentration, ranging between 31 and 103 CFU/100 ml. Irrigation ditches were significantly higher than the Dungeness River as well.

Fecal coliform data from adjacent marine waters was also analyzed between 1998 and 2008. Over 1,200 FC observations from 13 stations within Dungeness Bay were monitored monthly by the Washington State Department of Health as part of the National Shellfish Sanitation Program. Similar to the freshwater data, there was no significant increase or decrease in FC for the time period examined, although 2002 had the highest geometric mean concentration of all years and individual station trends did exist. Again, there was a distinct seasonal trend; however the pattern was the opposite of that observed at the freshwater stations, with significantly higher FC concentrations found during the wet season in marine waters compared to the dry season.

The evaluation of effectiveness for mitigating FC in the Dungeness watershed focused primarily on concentration data, rather than data based on in-stream loading (i.e. concentration times flow). Flow information was collected from a number of TWG monitoring stations, however it was not consistently available, and an in-depth analysis of loading was impractical. FC loading is an important concept with respect to inputs transported to the marine environment and shellfish harvest areas. An examination of FC concentration vs. loading was examined at two sites with adequate data; one site was on the Dungeness River at Mile 0.8 with relatively large flow, and one was an irrigation ditch that emptied into the Bay. While the concentration at the irrigation ditch was higher than the Dungeness River, the FC loading was several orders of magnitude greater at the Dungeness River site.

Nutrient Trends

Nutrient samples were collected from selected freshwater stations during routine FC monitoring as part of the TWG study (2005 through 2008). Over 830 nutrient observations were analyzed, including phosphate (PO_4), nitrate (NO_3), nitrite (NO_2), ammonia (NH_4), total nitrogen (TN) and total phosphorus (TP). For a general reference, nutrient data was compared to historic data (nitrate and phosphate) collected at another location in the upper Dungeness River between 1959 and 1970. For the most part, recent nutrient levels in the lower Dungeness watershed were not very different than historic values, although a direct site comparison could not be made. There were, however, several trends in the data that warrant further investigation.

Ammonia concentrations were slightly elevated at all Dungeness tributaries and Bell Creek compared to those detected in the River or Johnson Creek. In addition, ammonia levels were an order of magnitude higher at Golden Sands Slough, another freshwater station close to the Bay. Ammonia is generally found in areas with low oxygen availability (i.e. groundwater) and is rapidly oxidized to nitrate in contact with surface waters. Its presence in surface waters, even at low levels, could indicate close proximity to potential sources such as septic systems or agricultural runoff. There were minimal seasonal changes noted in ammonia concentrations, another possible indication of septic system influence since septic system input generally varies less by season than other anthropogenic nutrient sources incorporated into seasonal runoff. Total inorganic nitrogen (TIN) was higher in Matriotti Creek, Bell Creek, Golden Sands Slough and the irrigation ditches compared to other water bodies and stations. TIN is an indicator of a number of possible anthropogenic inputs. Overall, the TIN data was higher during the wet season compared to the dry season, a possible indication of anthropogenic runoff. PO_4 and TP concentrations showed a similar trend of elevated concentrations in Bell Creek, Golden Sands Slough and the irrigation ditches, with higher concentrations during the wet seasons compared to the dry season.

There was no significant correlation between nutrients (NH_4, NO_3, NO_2, TIN, TN, PO_4, and TP), freshwater FC concentrations, and daily rainfall determined for the days of sample collection. The lack of a statistically significant correlation may be indicative of varying sources of FC and nutrients; however analysis of rainfall patterns over a longer duration might demonstrate a correlation.

Irrigation Piping and Septic Repair Effectiveness

Two BMP demonstrations conducted during the TWG study (irrigation piping and septic repairs) were analyzed on a site specific scale to determine their effectiveness at removal of FC bacteria and/or nutrients. A third BMP (mycoremediation) was analyzed for effectiveness in a separate report (Thomas et al. 2009). To the extent possible, water samples were collected upstream and downstream of each BMP activity, as well as before and after implementation of a BMP. Piping irrigation ditches is considered a BMP for water conservation by preventing conveyance losses. Since the water conveyance system is enclosed in a pipe, the possibility of contaminants entering the system is greatly reduced, and if the pipeline is closed at the end, there is no spilling of excess tailwater at the downstream end of the irrigation system.

Monitoring for the effectiveness of irrigation piping was problematic in the sense that downstream samples could not be collected in most cases since the source water was eliminated. Median concentrations from the two upstream stations were 10 and 128 CFU/100 ml. At one downstream location, the tailwater from a bluff ditch station (IRR-3) that emptied into the Bay was monitored after piping was complete because regulations required that a stormwater conveyance ditch be reconstructed above the pipe to continue to convey runoff. After piping, the FC concentration in the stormwater runoff conveyance was not significantly different than before the piping. Further analysis examined the impact of piping on tailwater discharge into Dungeness Bay, comparing data before and after the piping at three marine monitoring sites located near the freshwater bluff ditch sites. One marine station, DOH-110 was significantly different before and after piping. However, the geometric mean at this site before piping was 7 CFU/100 ml and after the piping was 4 CFU/100 ml. While this was statistically significant, it has little meaning from a water quality improvement standpoint.

A number of benefits of irrigation piping can clearly be demonstrated such as water conservation, reduced ditch maintenance and efficient water delivery, however the empirical evidence of reduction in FC was not clearly apparent from this study. In the case where an irrigation ditch was piped to eliminate tailwater, but the piped ditch closely coupled the path of a stormwater runoff conveyance into the Bay, the benefits were reduced. However, the potential source of contamination to this ditch is from a much smaller geographic area than prior to piping when several miles of open irrigation ditch led to this discharge location.

Effectiveness monitoring of a second BMP activity, septic system repairs, was examined as part of the TWG study. Nine direct discharge septic repairs (out of a total of 53 TWG repairs) were completed and analyzed for FC bacteria and nutrient removal. Samples were collected upstream and downstream of each septic repair where possible, as well as before and after the repair. In all cases, the nearest routine monitoring station, either upstream and/or downstream of a repair, was used for analysis. In general, for almost all septic repairs there was no significant difference between upstream and downstream FC levels based on the closest TWG monitoring site. In addition, there was no significant difference before and after a septic repair at those monitoring sites. Nutrients were examined in the same way, however in most cases there was not enough nutrient data to allow an evaluation of the repair effectiveness. Of the three repairs that could be evaluated, one repair showed a significant reduction in nitrite between the upstream and downstream station, before and after the repair. In this case the sample locations were relatively close to the repair, whereas results from other septic repair locations were confounded by a greater distance between the monitoring sites and the location of the repair.

While the benefit of implementing septic system repairs is clear, the monitoring method used to detect repair effectiveness, in hindsight, was not sensitive enough to detect a change at the site specific or local scale. Closest established monitoring stations were used, regardless of the location of the repair, rather than establishing monitoring stations in close proximity to repair locations. Hence, a statistical decrease in FC contamination as a result of septic system repairs was not observed, in part because the monitoring sites were located too far away from the repair to detect a difference. This coupled with the high natural variability in FC concentrations resulted in no statistically significant findings. The nutrient results from one case where a significant decrease was detected indicate that monitoring stations placed in closer proximity to the repair or source in question would have a better chance of detecting a significant difference. This type of monitoring could be used for detecting failing septic systems or evaluating repair effectiveness, if monitoring locations were selected specifically for that purpose.

Sample Design and Monitoring Considerations

In this study the analysis of water quality data was conducted as multiple scales; site specific as well as landscape (i.e. river, tributaries, Dungeness Bay). At the local scale water quality parameters were monitored prior to and following BMP implementation activities (e.g. irrigation piping, septic repairs). Where possible, monitoring also occurred upstream and downstream of BMP sites. At a landscape scale, water quality was monitored at stations that had been selected in earlier years due to suspected water quality problems, and/or stations that had been included as part of a prior TMDL investigation conducted in 1999-2000. While analysis of these sites allowed for continuity of a longer term data record via continued monitoring through the TWG program, the locations were not originally established in such a manner that would allow for a statistically robust examination of overall landscape trends in the watershed. Moreover, the monitoring sites were not optimally located to evaluate BMP effectiveness. The spatial and temporal sampling approach and analysis was limited by a variety of factors including property access, seasonal availability of running water (e.g. irrigation ditches), and budget constraints. Any trends noted in the data should be viewed with these constraints in mind.

Recommendations

The effectiveness monitoring study provided an opportunity for the first time, to explore surface water quality data in the Dungeness watershed from a broader perspective than has generally been possible in the past from smaller, specifically targeted projects. For this study, datasets from past, recent, and ongoing programs in the Dungeness watershed and Dungeness Bay were combined to evaluate overall trends from the past decade. In addition, the success of selected BMP demonstrations was evaluated at a local scale, leading to an understanding of the importance of sample design in evaluating effectiveness. The Effectiveness Monitoring study has provided new insights regarding the status of water quality in the watershed, highlighted questions and identified areas in need of broader evaluation and modifications to the existing water quality monitoring strategies. Implementing these recommendations and evaluating the results, as an integral part of an ongoing adaptive management approach, will better inform concurrent management actions to improve water quality in the Dungeness watershed.

Based on the results from this effectiveness monitoring study, we offer the following recommendations:

- **Evaluate Results in Broader Context -** Evaluate the FC and nutrient results from the effectiveness monitoring study in the broader context of other types of studies that have been conducted in the Dungeness watershed (e.g. TMDL's, Dungeness Bay circulation study, Microbial Source tracking) as well as ongoing studies (e.g. TMDL effectiveness monitoring) in order to develop an improved framework for moving forward with modifications to the existing water quality monitoring strategies (see next three bullets)..

- **Fecal Coliform Water Quality Monitoring Strategy Modifications** - Re-assess and modify the overall fecal coliform water quality monitoring strategy for the Dungeness watershed and develop sample designs for 1) a statistically balanced long–term dataset that will allow evaluation of landscape-scale watershed changes, 2) continued acquisition of evaluative data as site specific questions arise, and 3) storm water runoff collection and analysis. Incorporate data collection of both concentration and loading information as equally important components.

- **Nutrient Water Quality Monitoring Strategy Modifications** - Incorporate nutrient sampling into site specific and long-term sampling designs in the watershed. This is an important water quality parameter that can provide additional insight regarding ground water conveyance and surface water runoff contaminants (e.g. human and animal waste, fertilizers, industrial pollutants).

- **On-Site Septic System Water Quality Monitoring Strategy Modifications** - Continue to refine tools to detect on-site septic system failures and evaluate septic system repairs. Evaluate a modification of the effectiveness monitoring approach that incorporates monitoring stations located in closer proximity (upstream and downstream) of a targeted site, and incorporate both FC and nutrient collection (ammonia and nitrate) into the monitoring design.

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1.0 Introduction

In 2004, the Jamestown S'Klallam Tribe was awarded a U.S. Environmental Protection Agency (EPA) Targeted Watershed Initiative grant to focus surface water cleanup efforts in the lower Dungeness Watershed. The Targeted Watershed initiative was established in 2003 to encourage innovative community-based approaches and management techniques to protect and restore clean water in the nation's watersheds. The Dungeness Targeted Watershed Initiative work plan focused on key watershed restoration activities recommended in local watershed planning strategies (HDR, 2006) (Clean Water Work Group, 2000) (Elwha-Dungeness Planning Unit, 2005) for water quality and flow restoration. These activities were priorities from the Detailed Implementation Strategy, a plan to address problems identified in two Total Maximum Daily Load Studies. The following tasks are included as part of the Initiative:

Task 1 a Microbial Source Tracking study to more precisely define pollutant sources;

Task 2 innovative best management practice (BMP) demonstrations (and market-based incentives for BMP implementation) related to water quality treatment or water conservation including a mycoremediation treatment demonstration, septic system maintenance, and irrigation piping; and

Task 3 an Effectiveness Monitoring study, to compare the effectiveness of various BMP activities within the watershed and examine the historic context within the watershed.

Under contract with the Jamestown S'Klallam Tribe and with input from the Dungeness Clean Water Work Group, Battelle (Pacific Northwest Division) Marine Sciences Laboratory led *Task 3* Effectiveness Monitoring Study which is the subject of this report.

1.1 Background

The Dungeness Watershed is located on the Olympic Peninsula of northern Puget Sound in Washington State. The river originates in the Olympic Mountains and flows 32 miles downstream through wilderness, forested, commercial, agricultural and residential areas to Dungeness Bay. The 200-square-mile watershed harbors more than 200 fish and wildlife species and is an important stop for migratory waterfowl. Dungeness Bay is home to the Dungeness National Wildlife Refuge, and serves as a refuge, preserve, and nursery ground for native birds, fish and shellfish species. The Dungeness riparian corridor has been identified as an Important Bird Area by the National Audubon Society.

For over 20 years, local and regional entities and collaborative partnerships have worked to protect and maintain ecosystem functions in the Dungeness Watershed. However, the area has been slowly converted from mixed forest/agricultural to mostly agricultural and commercial/residential land uses. The Dungeness River supports an extensive irrigation network serving the agricultural and residential community. In recent years, human induced impacts have impaired the natural function of tributaries and the river and bay. These impacts are primarily exhibited through habitat and water resource alteration such as: bank armoring, dikes, stream straightening, water withdrawal and native vegetation removal. A variety of watershed health problems have ensued, including the listing of four salmonid species under the Endangered Species Act and closure of Dungeness Bay to shellfish harvesting beginning in 2000 (Sargeant, 2004) due to high levels of fecal coliform (FC) bacteria. Although some activities have been implemented to improve watershed health, failing septic systems, impaired in-stream flows, pollutant inputs from storm water runoff, and floodplain development continue to persist.

1.2 Project Objectives and Report Organization

The objectives of the Dungeness Targeted Watershed Initiative fall under a larger body of on-going activities including the short- and long-term goals of the watershed plan for Watershed Resource Inventory Area (WRIA) 18, which includes the Dungeness River (Elwha-Dungeness Planning Unit, 2005). The long-term goals of the Dungeness Targeted Watershed Initiative that are shared with the long-term goals in the WRIA 18 plan include the following:

- Increase the use of BMPs associated with improving water quality.
- Improve the water quality in the Dungeness Watershed and Bay to meet shellfish harvest and freshwater standards, and to meet restoration targets.
- Mitigate the impacts of storm water runoff.
- Improve in-stream flows for ESA-listed fish.
- Remove Dungeness River from the 303(d) list (for both FC and low in-stream flows).

The short-term goals, which were expected to be achieved within the Dungeness Targeted Watershed Initiative's timeline, include the following:

- Identify species-specific pollutant sources (addressed by *Task 1*);
- Apply innovative BMPs (addressed by *Task 2*);
- Reduce the number of faulty septic systems (addressed by *Task 2*);
- Improve the irrigation system efficiency (addressed by *Task 2*);
- Enhance public awareness of pollutant sources and pollutant prevention techniques (addressed by all tasks, and public outreach plan).

Complementing the above goals, the Effectiveness Monitoring Study (*Task 3*) considered the following questions:

- What are the temporal and spatial trends for FC bacteria and nutrients in the Dungeness watershed?
- To what degree are the targeted BMPs (irrigation piping, septic repairs, mycoremediation) effective at reducing nutrient and FC levels?
- What are the differences in cost with respect to the effectiveness of each BMP?
- What is the effectiveness of training and community outreach in reducing bacterial/nutrient pollutants?

This document reports the results and conclusions of the Effectiveness Monitoring Study, the monitoring and BMP evaluation component of the Dungeness Targeted Watershed Initiative. It focuses on the first two study questions (i.e. temporal and spatial trends of bacteria and nutrients), and assessing the technical effectiveness of the irrigation piping (*Task 2d*) and septic repair (*Task 2b*) BMPs. Separate reports address *Task 1* – Microbial Source Tracking study (Woodruff et al., 2009) and *Task 2a*, the effectiveness of the mycoremediation BMP through a field site demonstration (Thomas et al., 2009). A discussion of BMP cost-effectiveness and community outreach will be included in a final Targeted Watershed grant summary report.

This report is organized into the following sections:

- Section 1.0 provides an introduction and background to the overall project.
- Section 2.0 discusses the field sampling and analytical methods, statistical limitations based on the sampling design, and the statistical analysis.
- Sections 3.0 and 4.0 discuss the FC trends for the freshwater sites and marine sites, respectively.
- Section 5.0 focuses on site-specific BMPs (i.e. irrigation piping and septic repairs) that were implemented as part of the Dungeness Targeted Watershed Initiative.
- Section 6.0 provides descriptive statistics and general trends observed in nutrient data, which were primarily collected during the Targeted Watershed Initiative grant period.
- Section 7.0 discusses conclusions and recommendations for continued and future actions.

1.3 Overview of Project Area

The project area for this task encompasses sites on and near the Dungeness River, its tributaries and creeks, ditches and Dungeness Bay (Figure 1). The freshwater sites shown on this map were sampled on a monthly basis as part of the Targeted Watershed Initiative between 2005 and 2008. Many of these sites (Dungeness River, Matriotti Creek, Meadowbrook Creek, irrigation ditches that empty into the Bay) were investigated in the late 1990's as part of a bacteria Total Maximum Daily Load Study (TMDL) conducted by Washington State Department of Ecology (Sargeant, 2002). Two additional impaired streams, Bell and Johnson Creek, have also been monitored historically, and continued to be monitored during this study. These streams empty into Sequim Bay and were included in the overall analysis. All sites were sampled for FC bacteria and a subset of stations was sampled for nutrients as well.

The Washington State Department of Health (DOH) has sampled thirteen marine stations in Dungeness Bay (Figure 1) for FC bacteria since the 1980's. In the late 1990's increasing levels were reported near the mouth of the Dungeness River. Since that time, the elevated bacteria trend has continued and several shellfish harvest closures have been implemented in order to protect consumers from eating bacteria-contaminated shellfish. Of the marine sampling stations, two stations are within an open area for shellfish harvest year-round (Approved), four stations are in closed year-round areas (Prohibited) and seven stations are within an area open seasonally from February through October (Conditionally Approved) (Figure 1). These stations were all included in the historic trend analysis for Dungeness Bay. Nutrients were collected from a small subset of stations during a portion of the Targeted Watershed Initiative.

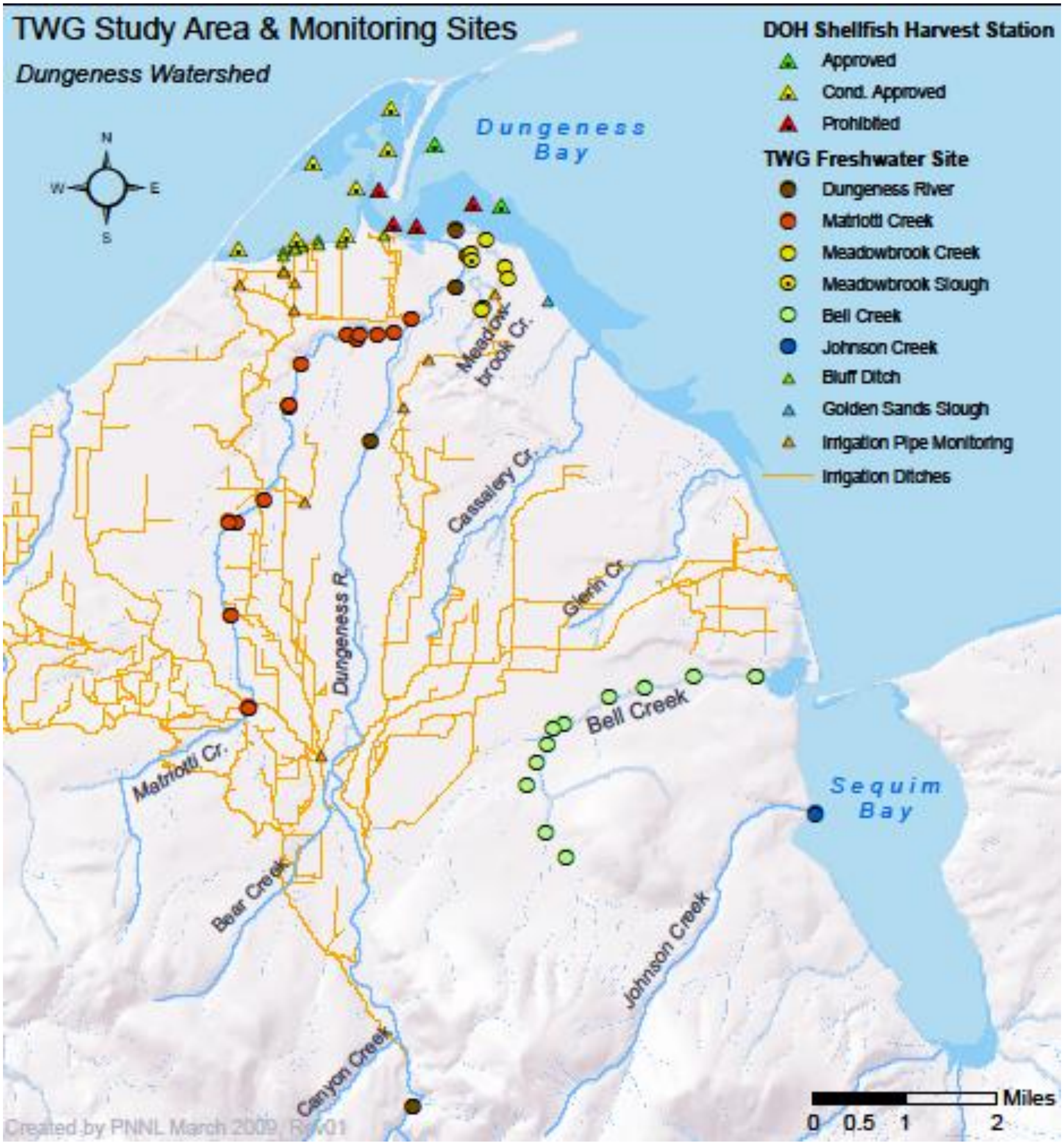


Figure 1. Map of Dungeness Watershed Showing TWG Monitoring Sites and Department of Health (DOH) Marine Monitoring Sites.

2.0 Sampling Methods and Statistical Design

2.1 Approach

In addressing the monitoring and BMP evaluation component of the Dungeness Targeted Watershed Initiative, both the local (site specific) scale and the watershed scale were considered. At the local scale, water quality parameters were monitored before and after installation of BMPs (e.g. irrigation piping, septic repairs, mycoremediation). Monitoring was conducted at ambient monitoring stations located upstream and downstream of the BMP sites on a monthly basis for FC bacteria and selected nutrients. Pre-established ambient sampling stations from the Lower Dungeness TMDL study (Sargeant, 2002) were used whenever possible for a long term data record, recognizing that these site locations were not originally designed to find trends in landscape patterns. At the watershed scale, FC and nutrient data were analyzed based on geographic location within the watershed (e.g. tributaries, creeks, ditches emptying into the Bay) and in Dungeness Bay. FC data were analyzed over a ten year time period. Very little historic nutrient data were available, hence the nutrient analysis focused on data that was collected primarily during this study (2006-2007) as well as some analysis of data collected during the TMDL study (1999-2000), and historic data included in the United States Geological Survey (USGS) National Water Information System (NWIS) database between 1959 and 1970.

2.2 Water Quality Sampling and Laboratory Methods

The Dungeness Watershed contains 546 miles of streams and tributaries with an average slope of 1% in the lower 15 miles (Elwha-Dungeness Planning Unit, 2005). There were approximately 66 freshwater monitoring sites in total, although some stations needed to be changed during the course of the study, or were re-positioned within the same general area. Of these sites, 42 are in-stream and 43% of those are less than 1 mile from Dungeness Bay or Sequim Bay shoreline and half are between 1 and 5 miles of the shoreline. The remaining 24 sampling sites are located within irrigation or run-off ditches, with 83% of those located within 1 mile of the shoreline. Salt water intrusion may influence nutrient samples within several irrigation ditch or run-off sampling stations and stations within slightly less than 1 mile up the Dungeness River (Kramer, Chin & Mayo, Inc., 1990).

2.2.1 FC Bacteria

Per our EPA-approved QAPP (Streeter, 2005), water samples were collected and analyzed on a monthly basis from all TWG sites unless the site was dry (e.g. irrigation ditches). Sampling was initiated in August 2005 and ended in January 2008. Samples were analyzed by the Clallam County Environmental Health Laboratory using Standard Method SM18 9222D (membrane filtration). All samples were analyzed the same day as collection. During most of the study, we were able to coordinate TWG sampling to occur on the same day as the Department of Health water quality monitoring at marine sites for shellfish harvesting.

2.2.2 Nutrients

Per our EPA-approved QAPP (Streeter, 2005), water samples were collected for nutrient analysis at the same time as FC samples from selected TWG stations, between August 2005 and January 2008, with the exception of total nitrogen (TN) and total phosphorus (TP) which were collected starting in March 2006. Nutrients samples were also collected from Department of Health marine monitoring sites (DOH Station 108 and 113). Samples were analyzed by the University of Washington (School of Oceanography Laboratory) following methods of Valderrama (1981). Samples were analyzed for total nitrogen (TN), nitrate (NO_3), nitrite (NO_2), ammonia (NH_4), total phosphorus (TP), phosphate (PO_4), and silicate (SiO_4).

2.3 Statistical Design and Analysis

2.3.1 Statistical Design Considerations

Historically, sampling locations in the Dungeness Watershed were selected in order to evaluate potential water quality problems such as failing septic systems, and to determine possible contributions from residential areas, small farms and businesses, or for TMDL-specific purposes. Those sites continued to be monitored, building on a long-term data record. However, original sample site selection was not based on a statistical design that would provide an unbiased watershed estimate of FC or nutrient concentrations through time and across the landscape. Further, sampling stations were not all consistently sampled over time. Sampling depended upon access permission, seasonal access, availability of running water, modifications or piping of irrigation ditches, failure or repairs of septic systems, and site specific interest. The difficulty in achieving consistent sample collection through time produced an imbalance in the number of samples collected between water bodies, locations within water bodies (i.e., river miles), and across years.

To reduce the effect of unequal sample sizes for the statistical analysis, stations were grouped by location (e.g. tributary, ditch) and by seasons (e.g., wet and dry seasons). However, since stations were often sampled when suspected of potential problems or were sometimes relocated when no longer accessible, a statistically rigorous and unbiased sampling design could not be followed. Therefore, any statistical trends presented in the data based on landscape pattern or condition should be considered hypotheses that might warrant further investigation.

2.3.2 Statistical Analysis

For all water quality samples, the geometric mean was calculated as the antilog of the mean of the log-transformed bacteria or nutrient data for the specified time period. For reporting purposes, the 90^{th} percentile was calculated as the antilog of the mean of the log-transformed data plus 1.281552 times the standard deviation of the log-transformed data. These calculations are consistent with the statistics used by the USEPA and the State of Washington for water quality assessments. A geometric mean tends to dampen the effect of extreme values that might bias the results if a straight average (arithmetic mean) were calculated. The geometric mean is especially useful when analyzing bacteria concentrations, as levels can frequently vary from 10 to 10,000 fold over space and time.

For statistical analysis of the monthly, seasonal, and annual trends, a daily mean of FC concentration was calculated for each sampling station. If multiple observations (including field duplicates) were taken in one day, the arithmetic mean produced a value greater than the geometric mean, and thus a more conservative estimate of the response. Observations that were less than the detection limit were given a value of 2 or 10 depending on the detection limit used by the analytical laboratory. Observations that were quantified as too numerous to count (TNTC) were either re-evaluated by the analytical laboratory and the new result used or they were not used. Daily average FC concentrations were transformed to the $\log_{10}$ (concentration+0.01) to reduce the inequality of the within group variances. The value of 0.01 added to each observation eliminated the zero values which existed in the database (i.e. values reported as less than the detection limit). Nutrient concentrations were also transformed to the $\log_{10}$ (concentration) for statistical analysis. Box and whisker plots were used to present general trends in the data. In these plots, the solid line within the box marks the median and the dashed blue line marks the mean. The lower and upper boundaries of the box are the 25th and 75th percentile, respectively. The whiskers (error bars) below and above the box indicate the 10th and 90th percentiles. All outliers are displayed as star symbols.

The overall objective of this analysis was to determine if any statistical trends in FC bacteria or nutrients could be detected in the Dungeness River, tributaries and creeks, ditches, or marine waters associated with the Dungeness watershed over time. An analysis of variance was conducted across and within water bodies using a generalized linear model to account for variability associated with rivers or tributaries (e.g. Dungeness River, Matriotti Creek, Bell Creek), river mile (e.g., location upstream from the mouth of the river or tributary), years, and month or seasonal effects. Variability associated with the tidal state (i.e. ebb or flood) was also evaluated using the Dungeness Bay data.

Several statistical models were used to explain the variability in FC concentrations in the different water bodies. Separate analyses were conducted for the three major systems: rivers and tributaries; irrigation and runoff ditches; and marine waters. For each of these systems, the variability in FC concentration was attributed to different effects: water body type (e.g., Matriotti Creek, bluff ditches), river mile (e.g., sampling location upstream from mouth), years, and months or season. Analyses used data from all tributaries in several generalized linear models shown below, representing these effects:

$$Y_{ijkm} = f\,(\text{Tributary}_i, \text{River Mile}_j, \text{Year}_k, \text{Month}_m) \qquad \text{Model 1)}$$

and

$$Y_{ilks} = f\,(\text{Tributary}_i, \text{Reach Location}_l, \text{Year}_k, \text{Season}_s) \qquad \text{Model 2)}$$

where reach location was defined as the mouth (river mile < 0.5), lower reach (river miles between 0.5 and 1 mile), middle reach (between 1and 5 river miles), and upper reach (greater than 5 river miles). These geographic locations are shown in Figure 2. Season was defined as wet (November – April) and dry (May – October).

Analysis was conducted for each individual tributary using the generalized linear model:

$$Y_{jkm} = f\,(\text{River Mile}_j, \text{Year}_k, \text{Month}_m). \qquad \text{Model 3)}$$

Finally, irrigation and runoff ditches not associated directly with the river or tributaries were analyzed in groups based on their general location within the watershed using the generalized linear model:

$$Y_{ikm} = f\,(\text{Station}_i, \text{Year}_k, \text{Month}_m). \qquad \text{Model 4)}$$

Dungeness Bay DOH stations were analyzed together and in groups based on their shellfish harvest classifications (e.g. Prohibited, Conditionally Approved, Approved) using Model 4. When possible, an analysis of the interaction between these effects was conducted to determine the consistency of observed patterns between tributaries within each season or consistency between locations within a given tributary for each season.

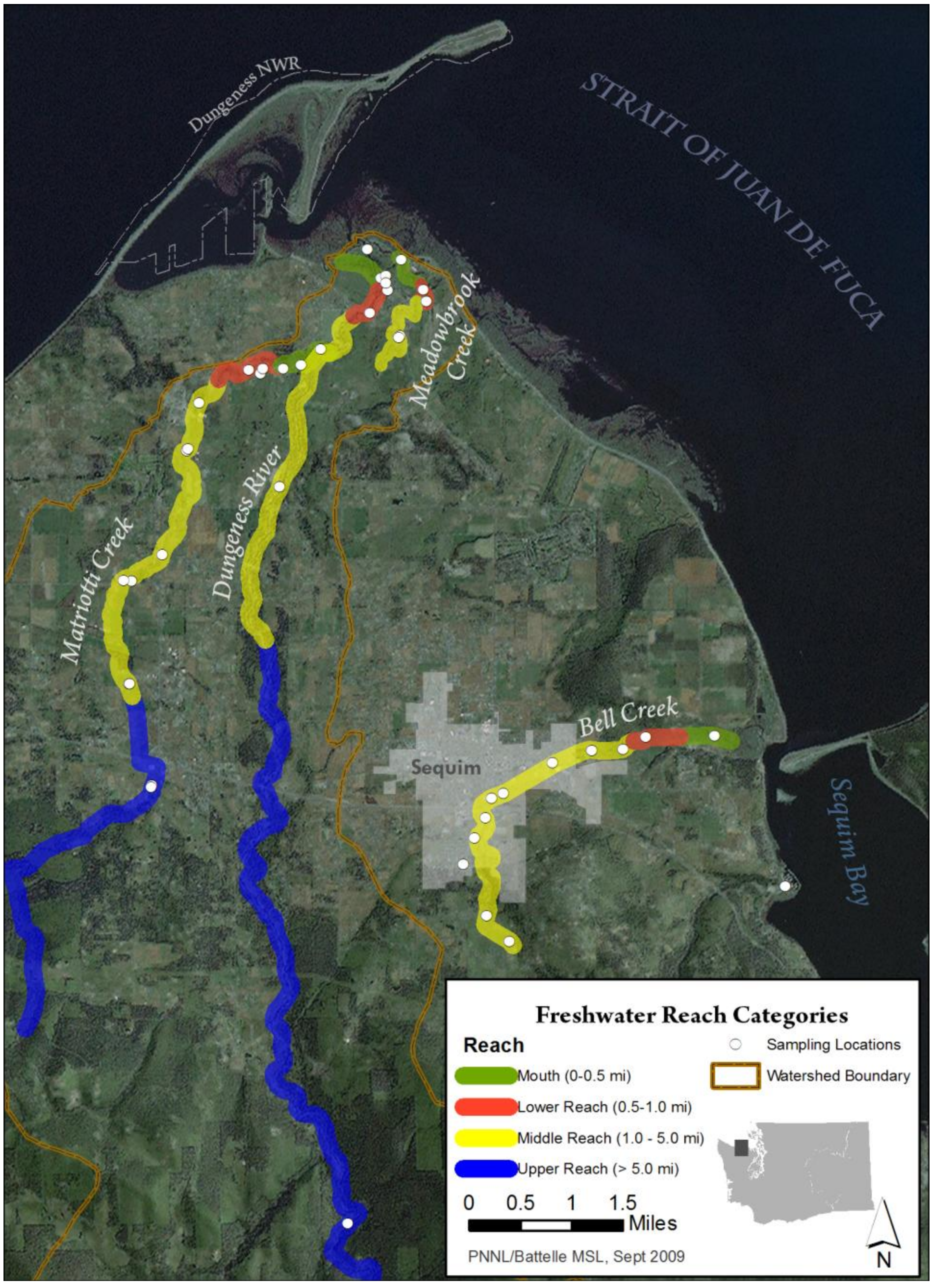


Figure 2. Map of Dungeness Watershed Showing the Reach Locations for each Tributary: Mouth (river mile <0.5), Lower Reach (0.5 – 1.0 mile), Middle Reach (1.0 – 5.0 miles) and Upper Reach (>5.0 miles).

Because of the unequal sample sizes, the sum of squares and means calculated for each effect in the generalized linear models were corrected for all other effects in the model (defined as Type III sum of squares and least squares means, i.e. LS-means). For example, the Type III sums of squares for the effect of Years in Model 4 are the additional variability in FC concentration explained by Year after having removed the variability explained by Station and Month. Likewise, the LS-means for each year (2006 and 2007, for example) are corrected for the variability explained by Station and Month. Tukey's Multiple Comparisons Test was used to test differences between LS-means within a given effect in the model (*i.e.*, Station, Years, and Months) to determine, for example, which station means were significantly different from each other.

Back transformed LS-means and associated upper 95% confidence limits provide an estimate of the geometric mean and an upper confidence limit corrected for all other effects in the model. These estimates were plotted to provide a visual assessment of trends for each effect in the model.

Nutrient data were analyzed in a similar manner as FC data, however, because of the shorter time period over which this data was collected, fewer trends by season or over years could be determined. Descriptive statistics including the median and 25^{th} and 75^{th} percentiles of the data were calculated to provide nonparametric ranges for each water body. The correlations between nutrients, rainfall, and FC concentrations were also calculated.

Because the overall sample size was so large for both the entire dataset and selected subsets of the data, statistically significant differences between sources, locations and time periods were expected among FC data. Thus, any differences detected should be examined closely in the proper context to determine if they are biologically relevant, within a threshold of concern.

3.0 FC Trends in Freshwater

3.1 Background and Approach

FC bacteria, which are common in the intestine of warm-blooded animals, are used as a water quality indicator of fecal contamination in the environment. They can indicate a direct discharge of waste from mammals or birds, agricultural and storm water runoff, or from human sewage. While FC bacteria may not be directly harmful, they can indicate a higher risk of pathogens present in the waters. In the Dungeness Watershed and Bay, FC bacteria have been monitored since the 1990's as one indicator of the overall health of the aquatic system. The Effectiveness Monitoring task focused on looking at historic FC data for the River, tributaries and nearby creeks, as well as examining site specific impacts of relatively recent BMP implementations.

Water quality samples for FC concentration (CFU/100 mL) were taken between 1998 and 2008 along the Dungeness River, tributaries, irrigation ditches, and the marine waters associated with the Dungeness watershed (Figures 3 and 4). Stations located along the River or tributaries were named to reflect the estimated river mile distance upstream from the mouth of the River or tributary (e.g. Dun 0.8 is the station located along the Dungeness River approximately 0.8 miles upstream from the mouth of the river). A total of 2,127 water quality samples of FC concentrations were used for analysis during this time period. Samples were taken from Bell Creek (11 stations; 529 observations), the Dungeness River (5 stations;

293 observations), Johnson Creek (1 station; 54 observations), Matriotti Creek (18 stations; 892 observations), Meadowbrook Slough (5 stations; 103 observations), and Meadowbrook Creek (5 stations; 256 observations) (Table 1). There were 264 FC concentration observations collected from irrigation ditches (24 stations) primarily between 2005 and 2008 (Table 2).

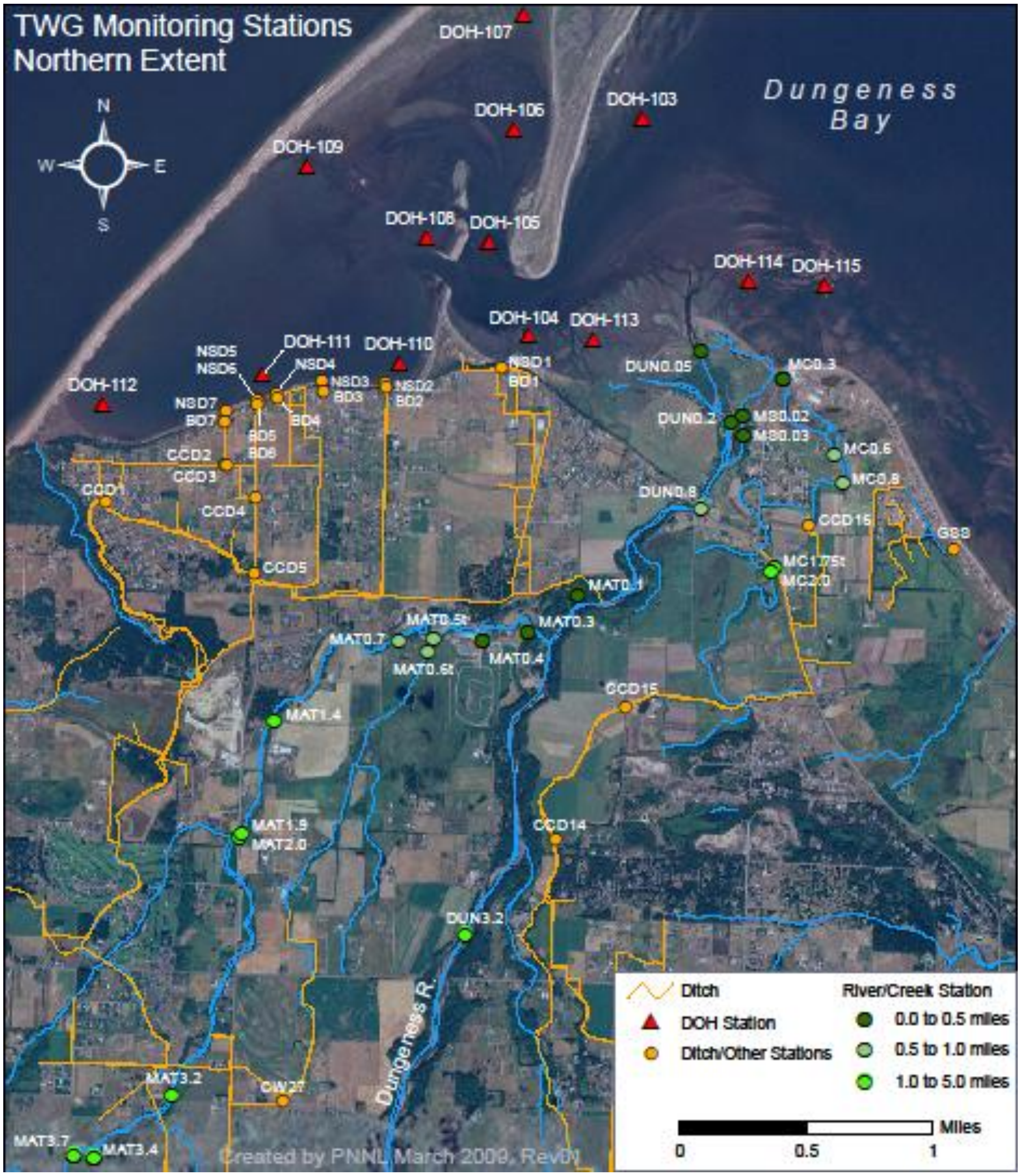


Figure 3. Map of Dungeness Watershed Showing the Northern Extent of Monitoring Station Locations

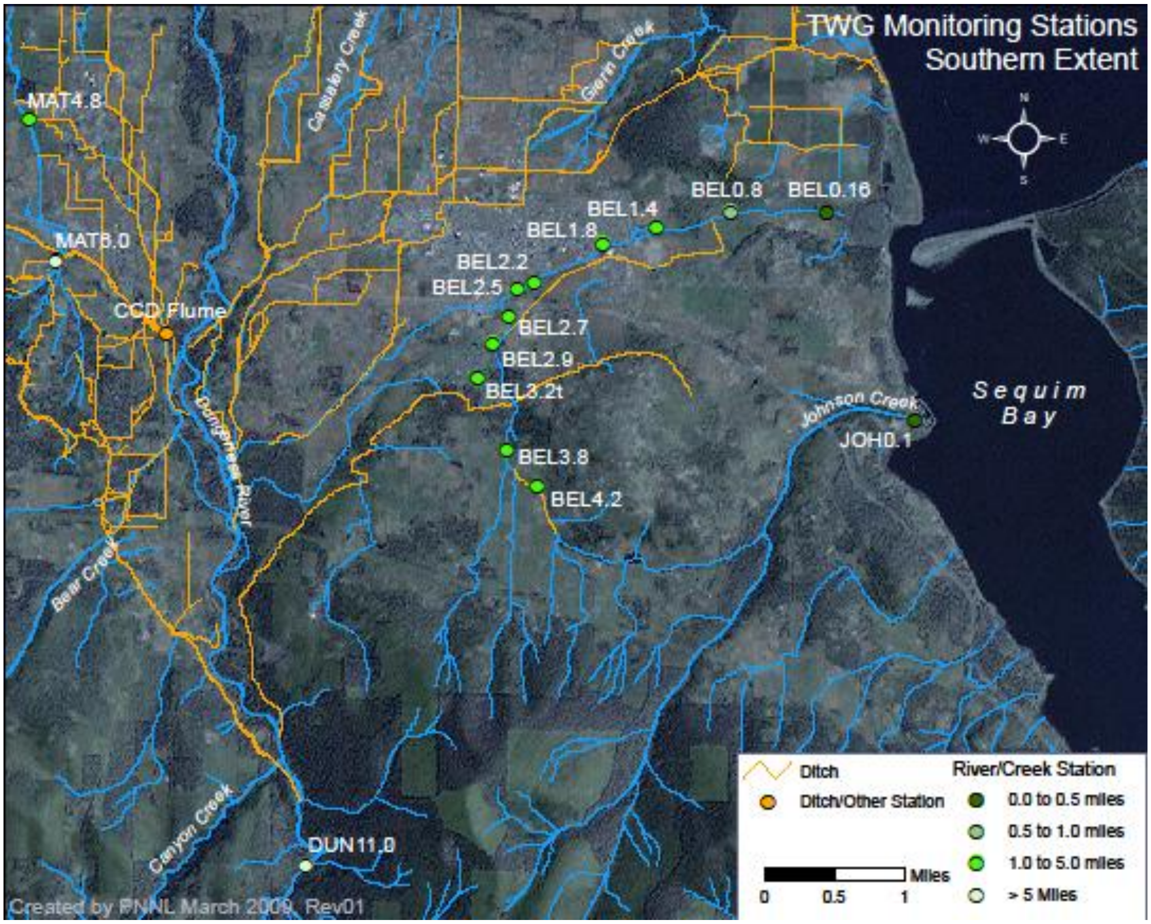


Figure 4. Map of the Dungeness Watershed Showing the Southern Extent of Monitoring Station Locations.

Table 1. Number of FC Concentration Observations Collected from the Dungeness River, Its Tributaries and Nearby Creeks Within the Dungeness River Watershed.

Station Names	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Grand Total
Bell Creek	9	5	46	44	74	47	58	90	71	78	7	529
Bel.16	4	4	7	8	11	6	9	12	12	12	1	86
Bel0.8			6	6	9		4	11	8	10	1	55
Bel1.4	4	1	7	7	8	5	8	9	7	9	1	66
Bel1.8	1		8	4	1			2				16
Bel2.2			5	6	8	6	3	9	11	12	1	61
Bel2.4			6	3	10	6	3	2				30
Bel2.7			3	4	6	3	8	10	11	12	1	58
Bel2.9					6	5	9	8				28
Bel3.2t					4	7	6	12	12	11	1	53
Bel3.8			3	5	5	4	4	6	1			28
Bel4.2			1	1	6	5	4	9	9	12	1	48
Dungeness River			12	35	38	29	29	39	56	51	4	293
Dun0.05			7						10	12	1	30
Dun0.2			1	12	15	10	10	12	12	12	1	85
Dun0.8			2	12	12	9	9	12	12	12	1	81
Dun3.2			2	11	11	10	10	12	12	12	1	81
Dun11.0								3	10	3		16
Johnson Creek/ Joh0.1	4	6			1	2	4	12	12	12	1	54
Matriotti Creek		27	167	109	106	86	74	107	106	102	8	892
Mat0.1		3	17	12	12	11	12	12	12	12	1	104
Mat0.3			9	11	11	11	6					48
Mat0.4			2	11	11	11	10	12	12	12	1	82
Mat0.5t								9				9
Mat0.6t		3	18	10	10	6	7	11	12	10	1	88
Mat0.7		3	18	11	11	8	4	12	12	12	1	92
Mat1.4		3	17	10	11	6	1					48
Mat1.9		3	19	11	13	12	7					65
Mat1.95t		3	20	11	14	12	11	8	2			81
Mat2.0								5	12	12	1	30
Mat3.2		3	15				6	12	12	12	1	61
Mat3.4							4	11	12	12	1	40
Mat3.42t							2	4	8	8		22
Mat3.7							3	11	12	12	1	39
Mat4.8		3	17	13	10	7	1					51
Mat4.8N				5								5
Mat6.0		3	15	2								20
Mat6.0t				2	3	2						7
Meadowbrook Slough			1	17	15	10	12	12	12	22	2	103
Mdsl.05			1	13	9	3	2					28
MS.02L				2	3		1					6
MS0.02									9	12	1	22
MS0.03						7	8	12	3	10	1	41
MS0.2R				2	3		1					6
Meadowbrook Creek		9	53	14	15	12	24	40	42	43	4	256
MC0.3		3	16	14	14	11	12	12	12	12	1	107
MC0.6							7	12	12	12	1	44
MC0.8		3	15		1	1	5					25
MC1.75t		3	13					4	6	7	1	34
MC2.0			9					12	12	12	1	46
Grand Total	13	47	279	219	249	186	201	300	299	308	26	2127

Table 2. Number of FC Concentration Observations Collected from Irrigation Ditch and Other Freshwater Monitoring Stations Within the Dungeness River Watershed.

Station Names	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Grand Total
CW27								5			5
Flume						3	25	34	30	3	95
CCD1							5	5			10
CCD2						1	5	4	1		11
CCD3						2	6	5	1		14
CCD4							5	3			8
CCD5							4	5			9
CCD14								2	9	1	12
CCD15								3	9	1	13
CCD16								2	10	1	13
Flume RM 7.5								5			5
Golden Sands Slough GSS	2	14	1	2	2	3	10	12	12	1	59
Irrigation-1						1	2				3
BD1						1	2				3
Irrigation-2		6				2	5				13
BD2		6				2	2				10
NSD2							3				3
Irrigation-3		5				2	12	9	6	1	35
BD3		5				2	9	7	6	1	30
NSD3							3	2			5
Irrigation-4						1	3		4		8
BD4						1			4		5
NSD4							3				3
Irrigation-5						1	7	5	4		17
BD5						1		1	4		6
NSD5							7	4			11
Irrigation-6						1	2	1	3		7
BD6						1			3		4
NSD6							2	1			3
Irrigation-7						2	7	8	5		22
BD7						2		6	5		13
NSD7							7	2			9
Grand Total	2	25	1	2	2	20	85	89	83	6	315

Descriptive statistics were used to characterize the FC distribution based on the water body type (e.g. creek, tributary, irrigation ditch). Table 3 and Figure 5 show the means and medians of FC concentrations in the Dungeness River and tributaries and other creeks in the study area. Plots of the FC concentrations for each TWG station between 1998 and 2008 are provided in Appendix A. Table 4 and Figure 6 show all other freshwater stations, generally grouped by water body type (i.e. irrigation stations, direct discharges to Dungeness Bay, and the bluff ditch stations separated according to sample location; top of the bluff (e.g. BD-2), or taken at the base of the bluff in the nearshore region (e.g. NSD-2). The sample location for these stations was dependent on season and tidal access. During a high tide, samples were collected on the top of the bluff. During a low tide, samples were taken at the nearshore bluff stations from freshwater seeps close to the base of the bluff and not in Dungeness Bay. When combined (e.g. BD-2 and NSD-2), these stations represented the direct discharge irrigation stations (IRR) in Figure 6.

Table 3. Median, 25th, and 75th Percentile (in parentheses) of FC Concentrations (CFU/100 mL) Collected from the Dungeness River, Its Tributaries and Nearby Creeks within the Dungeness River Watershed. [1]

Reach	Dungeness River n = 293	Meadowbrook Creek n = 256	Meadowbrook Slough n = 103	Matriotti Creek n = 892	Bell Creek n = 529	Johnson Creek n = 54
Mouth	12.0 (6.01 - 27.0)	40.0 (17.5 - 98.0)	48.0 (14.0 - 190)	103 (43.3 - 194)	36.0 (8.00 - 104)	18.5 (5.80 - 42.0)
Lower Reach	2.01 (2.01 - 5.01)	73.0 (21.0 - 187.0)	No Samples	30.5 (12.5 - 73.3)	14.0 (4.01 - 52.0)	No Samples
Middle Reach	8.01 (4.01 - 16.5)	35.5 (18.0 - 87.0)	No Samples	52.0 (18.0 - 129)	52.0 (14.8 - 124)	No Samples
Upper Reach	2.01 (2.01 - 2.01)	No Samples	No Samples	37.0 (14.0 - 118)	No Samples	No Samples

[1] Highlighted cells indicate locations with greatest median concentration.

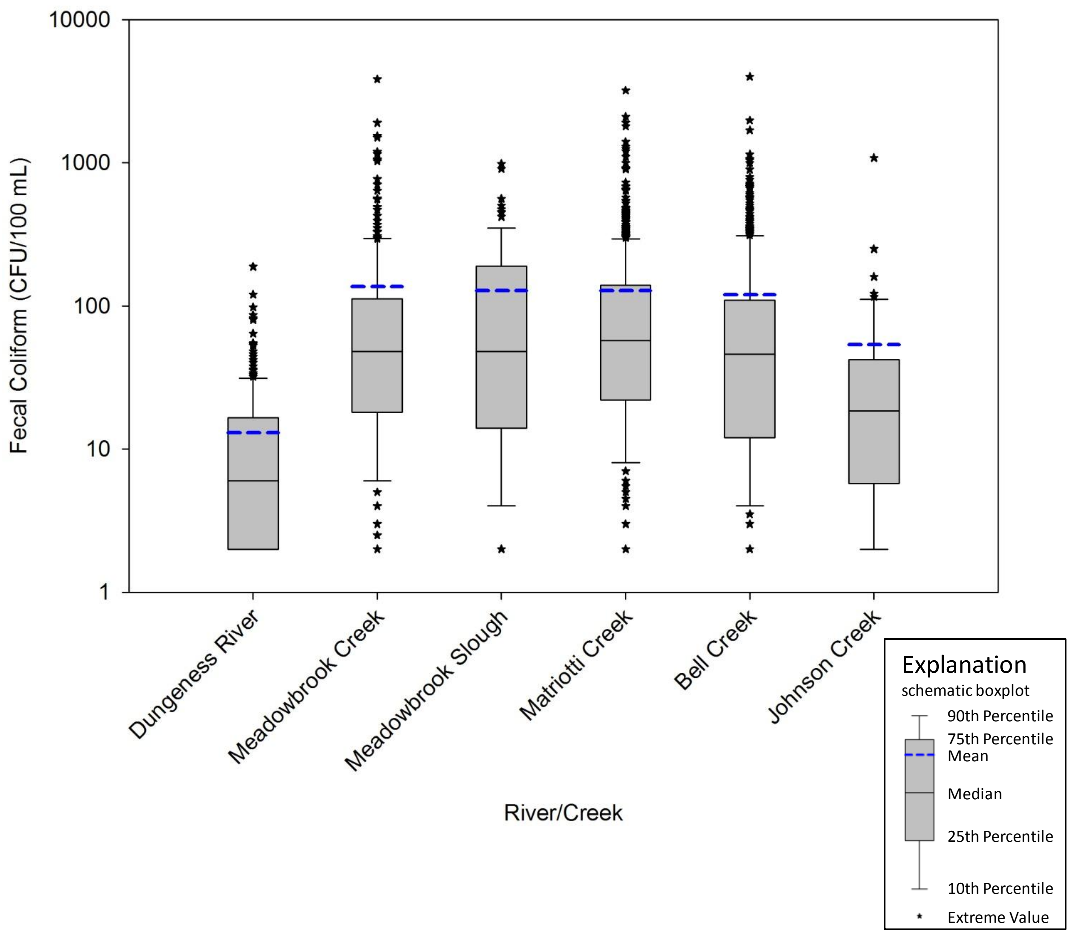


Figure 5. Box and Whisker Plot of Fecal Coliform Concentration Data Between 1998 and 2008 for Freshwater Water Body Tributaries and Creeks.

Table 4. Median, 25th, and 75th Percentile of FC Concentrations (CFU/100 mL) Collected from Irrigation Ditch and Other Freshwater Monitoring Stations within the Dungeness River Watershed. [1]

Irrigation Ditch	N	Median (25th and 75th Percentile)
Flume RM 7.5	5	10.0 (2.00 - 12.0)
CW27	5	128 (49.0 - 289)
CCD14 and CCD15	25	80.0 (25.0 - 458)
CCD1-CCD5	52	20.5 (6.50 - 94.5)
CCD1	10	83.0 (32.0 - 157)
CCD2	11	21.0 (4.00 - 142)
CCD3	14	5.00 (2.00 - 23.8)
CCD4	8	10.0 (3.50 - 23.0)
CCD5	9	58.0 (23.0 - 145)
CCD16	13	116 (10.0 - 273)
Golden Sands	59	44.0 (16.0 - 158)
Bluff Ditches	104	36.0 (7.00 - 168)
BD1	3	4.00 (3.00 - 8.00)
BD2	10	98.0 (23.5 - 163)
NSD2	3	616 (6.00 - 2,100)
BD3	30	52.5 (23.8 - 263)
NSD3	5	316 (184 - 526)
BD4	5	2,230 (1,092 - 8,735)
NSD4	2	264
BD5	6	3.50 (2.00 - 19.00)
NSD5	11	4.00 (2.00 - 32.0)
BD6	4	926 (6.00 - 1,832)
NSD6	3	37.0 (6.0 - 168)
BD7	13	12.0 (3.00 - 44.0)
NSD7	9	14.0 (10.0 - 64.3)
BD7 new	3	4.00 (3.00 - 8.00)

[1] Highlighted cells indicate locations with greatest median concentration by category.

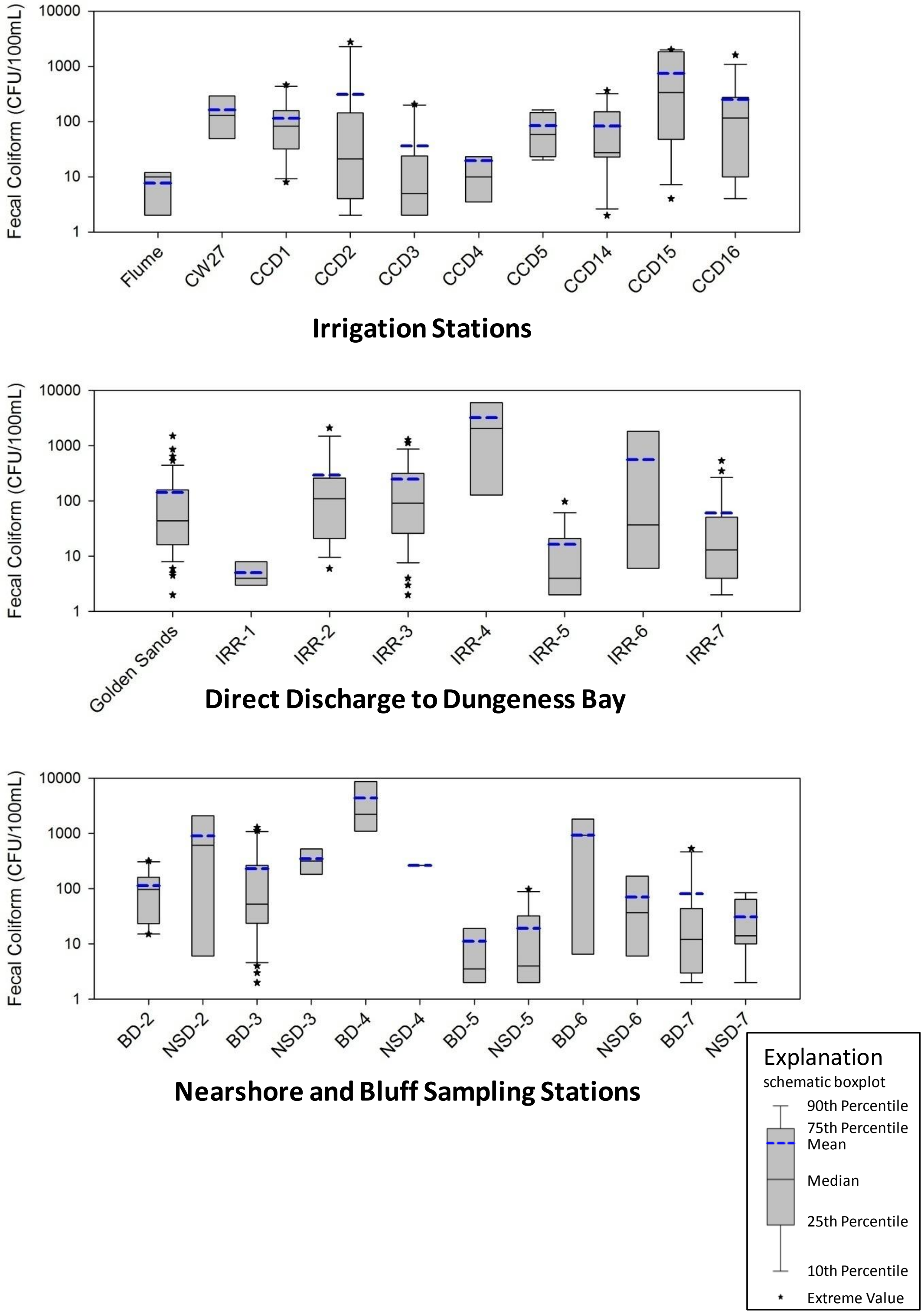


Figure 6. Box and Whisker Plot of Fecal Coliform Concentration Data Between 1998 and 2008 for Freshwater Sampling Stations, Grouped by Type or Location of Discharge

3.2 Overall Trends

Figure 5 shows that over the 10 year time-period between 1998 and 2008 the Dungeness River had the least amount of FC bacteria, based on concentration, of all the water bodies examined. Matriotti Creek had the highest concentration, although all creeks and tributaries show a similar median concentration (Table 3). The variability of FC concentration for the rivers and creeks is extremely high (i.e., several orders of magnitude in range). Extremely high variability exists for the other monitoring stations as well, including irrigation ditches (Figure 6). Several statistical models were used to partition the possible causes of variability in FC concentration for the tributaries and irrigation ditches. These methods are described above (Section 2.3.2).

A generalized linear model (Model 1, Section 2.3.2) was fit to all of the tributary FC data in order to better understand the relative impact of each tributary, the river mile, the month, and the year (1998 through 2008). There was no statistically significant difference in FC concentration between years based on the regression model ($n = 11$; $p = 0.97$). The geometric mean FC concentration for months of May through September, after correcting for the effects of each tributary, sampling year, and river mile is significantly higher than in the months of October through April ($p<0.001$) (left side of Figure 7). Because of the unequal sample sizes in each tributary and river mile, we then compared tributaries and sampling stations based on a more simplified model (Model 2, Section 2.3.2). In Model 2, the river miles are grouped into four reach location categories (Mouth, Lower, Middle, and Upper Reach), and months are grouped into 2 seasons to reflect average rainfall over the last 27 years in the Sequim. Based on rainfall data analysis, the wet season was determined to be between October and March and the dry season between April and September. Using this model, the estimated seasonal geometric mean FC concentrations, corrected for tributary, location, and year, was similar to the monthly geometric means, (i.e., the wet season mean was significantly less than the dry season mean , $p < 0.001$) (right side of Figure 7).

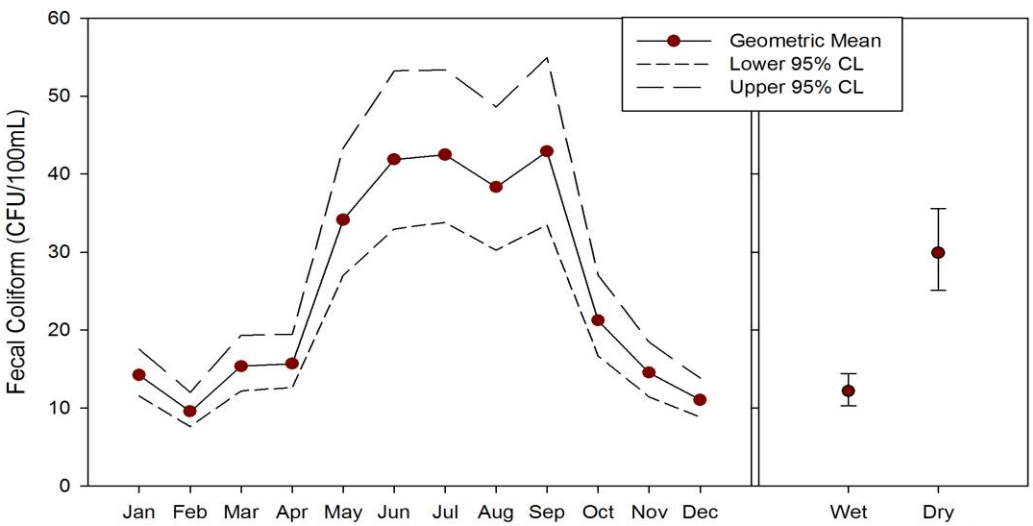


Figure 7. Geometric Mean of Fecal Coliform Concentrations for Each Month Corrected for Effects of Water Body Type, Sampling Year, and River Mile Location. The geometric mean for the wet season (Oct. through March) and the dry season (April through September) is shown on the right.

The Model 2 effects of tributary, reach location, and year were all significant (error d.f. = 2098; $p < 0.001$; Figure 8). The geometric mean (back-transformed from the LS-mean) of the Dungeness River FC concentrations was significantly less (4.8 with a 95% CI of 3.9 to 5.8 CFU/100 mL; Tukey's Test; $p = 0.001$) than Johnson Creek (11 with a 95% CI of 7.5 to 17 CFU/100 mL) which was significantly less (Tukey's Test; $p < 0.002$) than all of the remaining tributaries and creeks (Meadowbrook Creek – 23 to 36 CFU/100 mL, Meadowbrook Slough – 20 to 38 CFU/100 mL, Matriotti Creek – 32 to 44 CFU/100 mL, and Bell Creek – 25 to 36 CFU/100 mL). The means for each location within the river indicated a general decrease in FC concentration with increasing distance from the mouth. The mean FC concentration at the mouth reach location was significantly greater than all other reach locations (Tukey's Test; $p<0.001$), however, the mean FC concentration for the middle reach was significantly greater than the mean for the lower reach and greater than the upper reach (Tukey's Test; $p < 0.02$). The means for each year did not suggest a statistically significant increase or decrease in FC over the 10-year time frame of observations based on the Model 2 regression ($n = 11$; $p = 0.51$). Observations within years were highly variable with the year 2000 having the greatest overall geometric mean when corrected for all other effects (48 with a 95% CI of 39 to 59 CFU/100 mL).

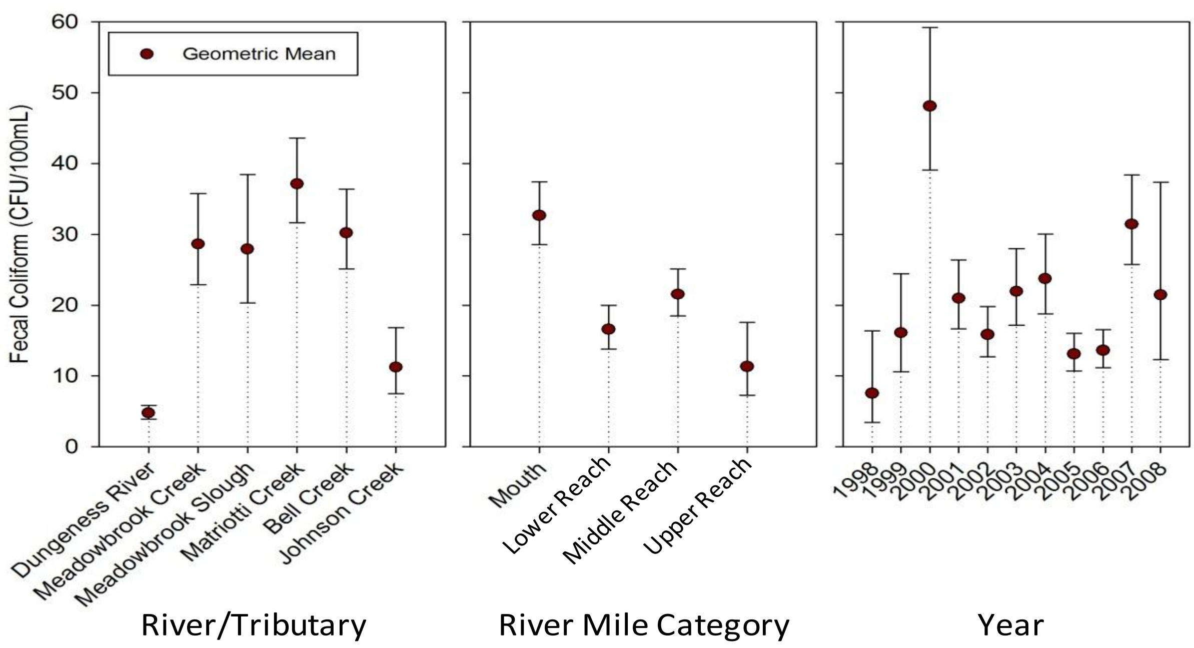


Figure 8. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations by Tributary/Creek (left), River Mile or Reach Location (center), and Year (right).

3.3 Trends by Tributary and Creek

Using the generalized linear Model 3(Section 2.3.2), trends were analyzed within individual tributaries, examining the effects of river mile (RM), year, and month . For the Dungeness River, the effects of RM, years, and month were significant (error d.f. = 269; $p < 0.001$; Figure 9) with the means of RM 0.8 (Station DUN0.8) and stations downstream significantly greater than RM 3.2 (Station DUN3.2) and upstream. Mean FC concentrations did not show a significant increase or decrease through time. However, the mean in 2007 was significantly greater than those in 2002 and 2006 (Tukey's Test; $p < 0.004$) and nearly significantly greater than 2003 and 2005 ($0.05 < p < 0.07$). Concentrations in February were significantly lower than June through November, and April was significantly lower than June, August, and September ($p < 0.05$).

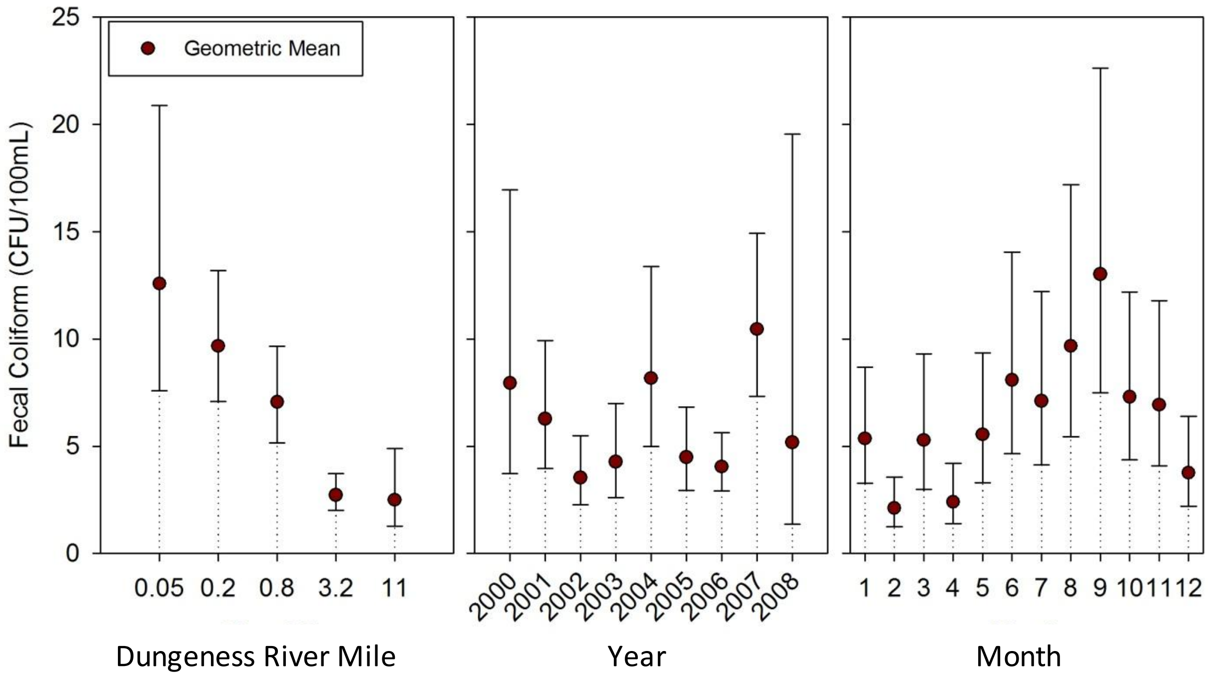


Figure 9. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations in the Dungeness River by River Mile (left), Year (center), and Month (right).

Meadowbrook Slough had only 4 sample locations, all below RM 0.5. The effects of RM, year, and month were all significant (error d.f. = 80; $p < 0.024$; Figure 10). Mean FC concentrations at RM 0.02 and 0.03 were significantly greater than at RM 0.2 (Tukey's Test; $p < 0.03$). There were no statistically significant differences between each year and each month (Tukey's Test; $p > 0.13$).

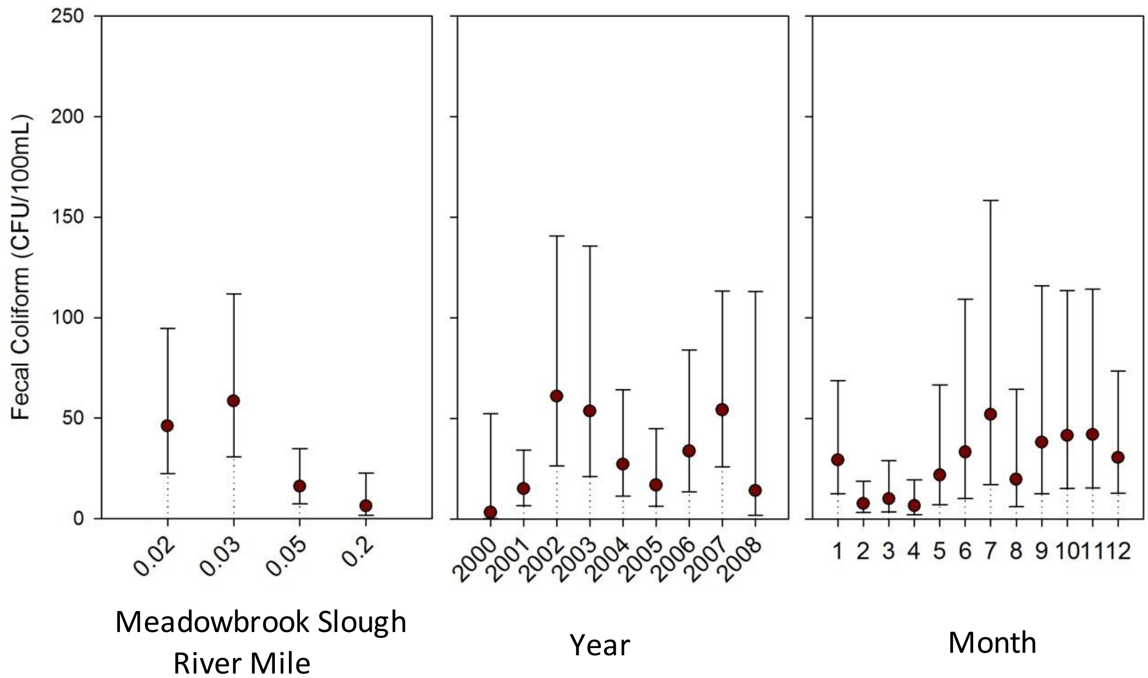


Figure 10. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations in Meadowbrook Slough by River Mile (left), Year (center), and Month (right).

Meadowbrook Creek had 5 sample locations: one below RM 0.5, 2 below RM 1.0, and 2 below RM5.0. The effects of year and month were significant (error d.f. = 231; $p < 0.001$; Figure 11), however, the effect of river mile was not significant ($p = 0.40$). The means for years did not suggest a significant linear trend through time based on the regression analysis ($n = 10$; $p = 0.20$). January and February had significantly lower mean FC concentrations than May through October (Tukey's Test; $p < 0.02$).

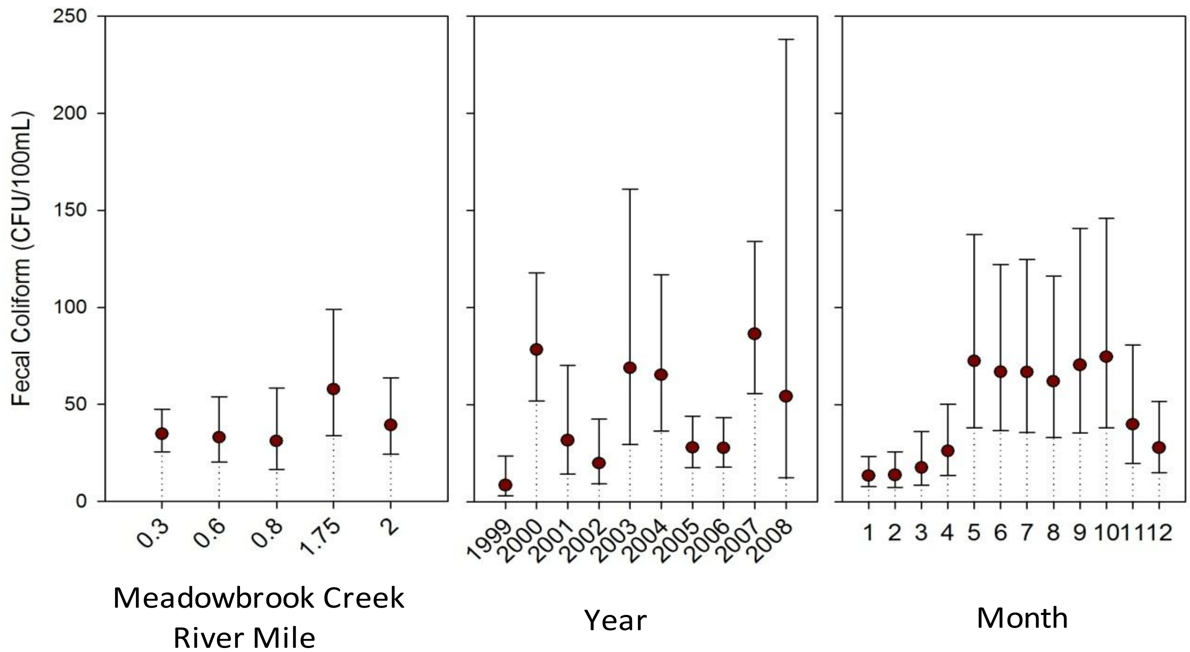


Figure 11. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations in Meadowbrook Creek by River Mile (left), Year (center), and Month (right).

Bell Creek had 11 sample locations: two below RM 0.5; one below RM 1, and nine below RM 5. The effects of river mile, year, and month were significant (error d.f. = 490; $p < 0.001$; Figure 12). There was not a significant linear relationship with river mile based on the regression analysis (n = 11; p = 0.39), however RM 0.16 and 1.4 were significantly less than RM 2.2, 2.4, and 2.9 (Tukey's Test; $p < 0.034$); RM 0.8 and 4.2 were significantly less than RM 2.2 through 3.8 (Tukey's Test; $p < 0.006$). The means for years did not suggest a significant trend either increasing or decreasing through time (Regression; n = 11; p = 0.49). January, March, and October had significantly lower mean FC concentrations than May through July (Tukey's Test; $p < 0.05$), February, April, November, and December had significantly lower mean FC concentrations than May through September (Tukey's Test; $p < 0.03$).

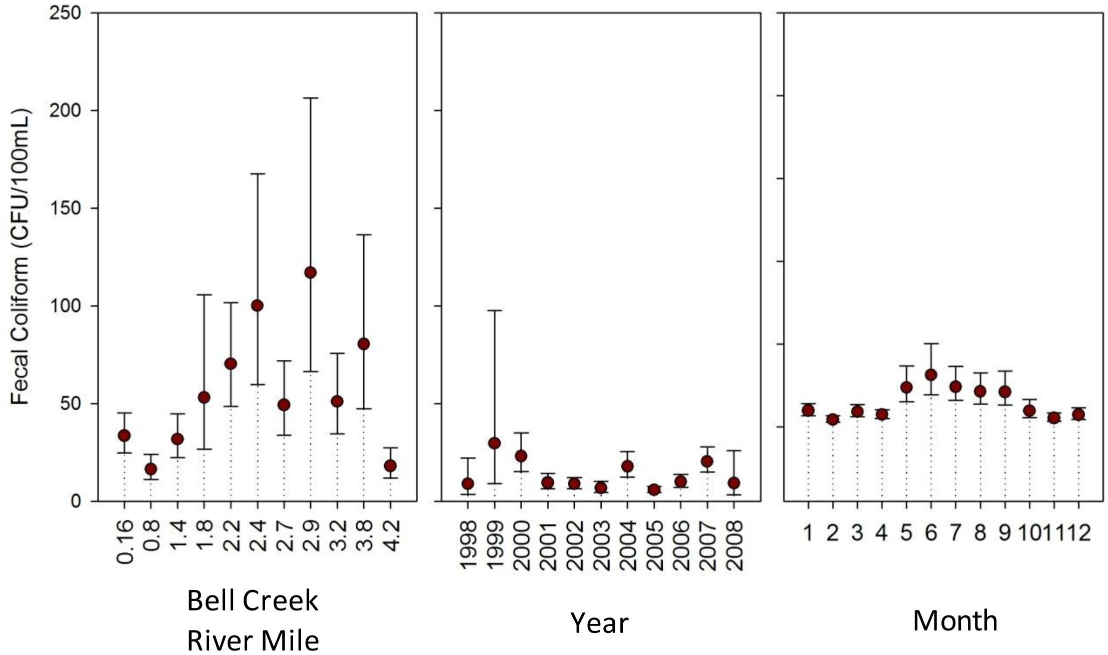


Figure 12. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations in Bell Creek by River Mile (left), Year (center), and Month (right).

Matriotti Creek had 17 sample locations: three below RM 0.5; three below RM 1, nine below RM 5, and one greater than 5 miles. The sample location at RM 6 was dropped after 2003. The Model 3 effects of river mile, year, and month were significant (error d.f. = 853; $p < 0.001$; Figure 13). There was a significant decrease in mean FC as the river mile increased based on the regression analysis (n = 16; p = 0.01). The FC means for years did not suggest a significant linear trend through time (n = 10; p = 0.18), however January, February, November and December had significantly lower FC concentrations than April through September (Tukey's Test; $p < 0.02$); March and October had significantly lower FC concentrations than May through September (Tukey's Test; $p < 0.04$); December had significantly lower FC concentrations than March and October (Tukey's Test; $p < 0.04$).

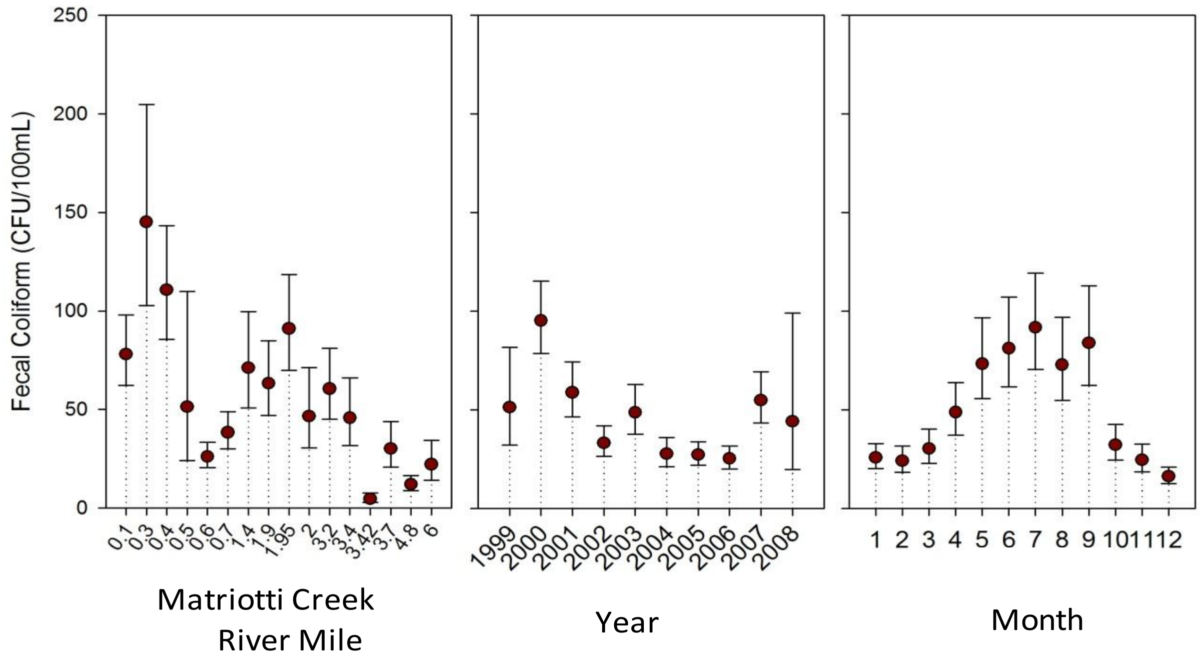


Figure 13. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentrations in Matriotti Creek by River Mile (left), Year (center), and Month (right).

The influence of Matriotti Creek on the Dungeness River was examined by looking at the difference in mean FC concentrations between two stations that were upstream and downstream of the confluence of Matriotti Creek with the Dungeness River. The concentration of mean FC at DUN0.8 downstream of Matriotti Creek was 10.8 CFU/100ml and was statistically greater than the concentration at DUN3.2, upstream of Matriotti Creek (5.8 CFU/100 ml) (t-test; d.f. = 76; $p = 0.003$; Figure 14).

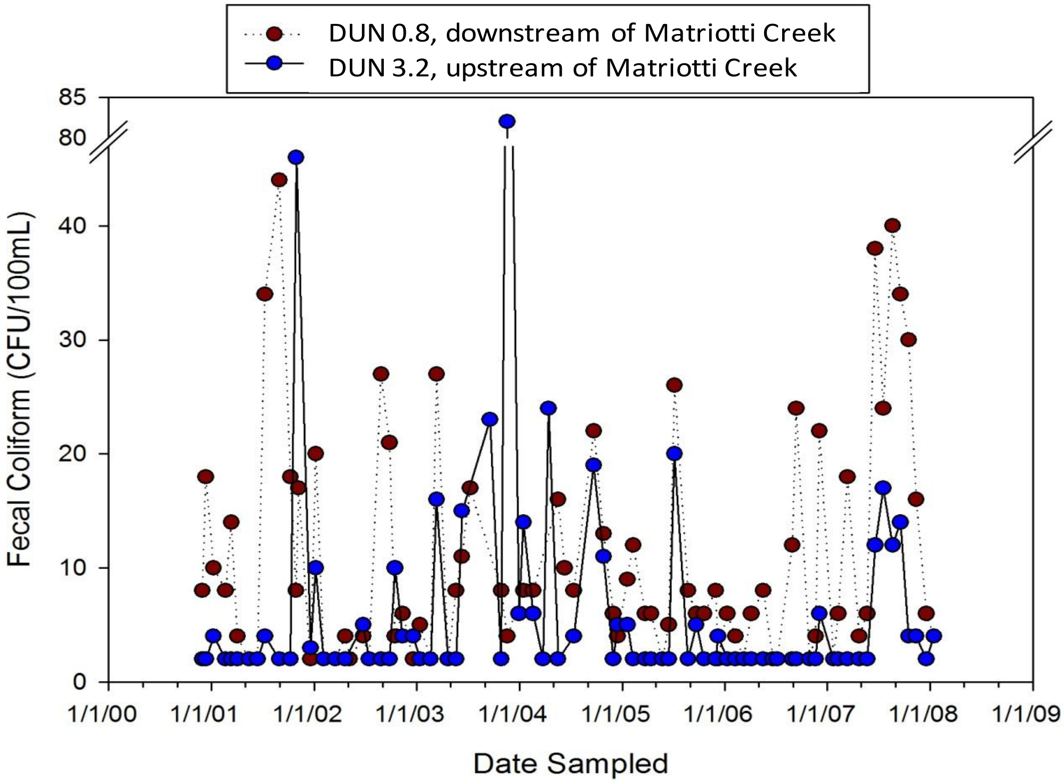


Figure 14. Fecal Coliform Concentrations in the Dungeness River at RM 3.2 and RM 0.8, Upstream and Downstream Respectively of the Mouth of Matriotti Creek.

3.4 Fecal Coliform Loading

FC loading is defined as the mass of bacteria transported to a receiving water body by a stream, stormwater outfall, irrigation ditch, or other discharge source over a given time period. For FC bacteria, loading is generally calculated as FC concentration (#/100 mL) multiplied by the flow discharge in cubic feet per second (CFS) to obtain loading reported as # FC/100mL x CFS. These loading calculations are frequently used in bacterial TMDL analyses in order to establish water quality targets based on loading and were used in the Dungeness Watershed TMDL (Sargeant, 2002). The FC seasonal or annual loads are calculated as arithmetic means of the instantaneous loads taken within the time period for relative comparisons. However the precision and accuracy of loading estimates increases with more frequent measurements of concentration and flow. In addition, a high percentage of loading into a receiving waterbody may occur during periods of high discharge. Therefore, monthly or quarterly estimates of concentration and flow may not produce accurate estimates of load and need to be qualified as such (Meals and Dressing, 2008).

The current evaluation of effectiveness was focused primarily on FC concentration data, not loading. Flow information was collected from a number of TWG monitoring stations when possible; however data were not consistently available for a variety of reasons. Because of this, and for reasons mentioned above, an in depth analysis of loading was not practical. However, recognizing these limitations with the TWG data, an estimate of the relative loading inputs from the Dungeness River at River Mile 0.8 and the Bluff ditches was calculated as an example (Figure 15). Even though the concentrations of FC are low in the Dungeness River compared to other tributaries and ditches, the relative loading of FC from the Dungeness River is several thousand times greater than the loading from the Bluff ditches, for example. This information needs to be taken into account in the overall evaluation of the impacts from the River, various tributaries, creeks, and ditches.

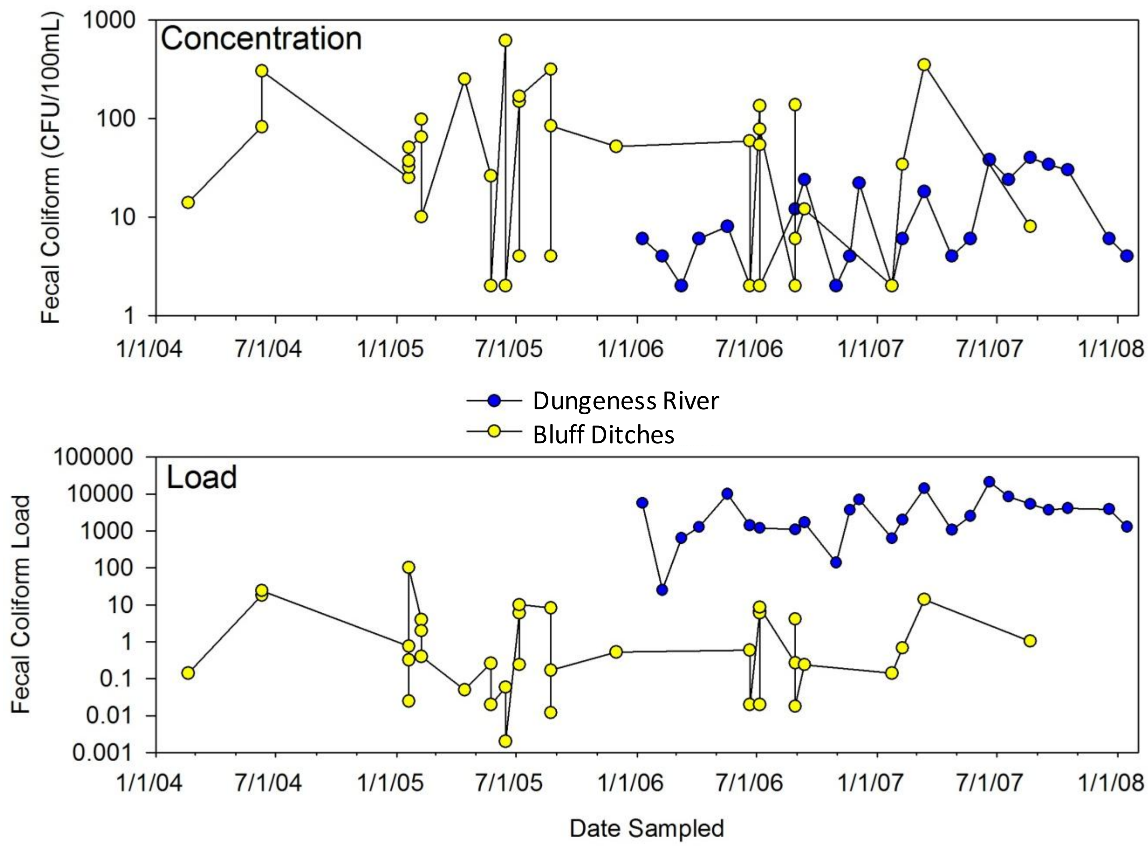


Figure 15. Fecal Coliform Concentrations (top) and Relative Load (bottom) Reported as CFU/100ml x Flow (cubic feet per second) for the Dungeness River and Bluff Ditches.

4.0 Fecal Coliform Trends in Dungeness Bay

4.1 Background and Approach

The Washington State Department of Health (DOH) reported increasing levels of FC bacteria in Dungeness Bay near the mouth of the River in 1997. Since that time, routine monthly sampling has been conducted at 13 stations in inner and outer Dungeness Bay (Figures 1 and 2). Several studies have examined the FC issues since then, including a Total Maximum Daily Load (TMDL) study (Sargeant, 2004), and bathymetric, circulation and reflux studies conducted in partial support of that TMDL by Rensel and Smayda (2001), and Rensel (2003). Since that time, DOH has reported annual status and trend summaries to monitor for fecal pollution in the Dungeness Bay shellfish growing area. DOH uses a systematic random sampling (SRS) method mandated by the National Shellfish Sanitation Program (NSSP) to monitor these areas. Samples are collected at marine monitoring stations at even intervals over time on a monthly basis. A minimum sample size of 30 consecutive results for any given station is used to classify or reclassify growing areas each year. These classifications may change as new FC data are incorporated into the analysis. These stations, shown in Figures 1 and 3 are currently classified into three harvest categories based on the geometric mean and estimated 90th percentile FC concentrations:

- Approved sites – Stations 103 and 115

- Prohibited sites – Stations 104, 105, 113, 114

- Conditionally Approved (closed November through January) – Stations 106, 107, 108, 109, 110, 111, 112

Our analysis examined the DOH marine data for Dungeness Bay from 1999 to 2008. There were 1,244 FC concentration samples collected and analyzed from 13 DOH marine stations noted above during this time period (Table 5). During the TWG study, sample collection dates were coordinated to occur on the same day as the freshwater sample collections.

Table 5. Numbers of FC Concentration Observations Collected by DOH in Dungeness Bay at Shellfish Growing Area Sites.

Station Names	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Grand Total
Approved for Harvest	12	12	22	12	18	23	24	24	23	20	190
103	6	6	11	6	9	11	12	12	11	10	94
115	6	6	11	6	9	12	12	12	12	10	96
Conditionally Approved	42	42	77	42	62	83	83	84	84	70	669
106	6	6	11	6	9	12	12	12	12	10	96
107	6	6	11	6	9	11	12	12	12	10	95
108	6	6	11	6	8	12	12	12	12	10	95
109	6	6	11	6	9	12	12	12	12	10	96
110	6	6	11	6	9	12	12	12	13	10	97
111	6	6	11	6	9	12	12	12	12	10	96
112	6	6	11	6	9	12	11	12	11	10	94
Prohibited from Harvest	25	24	44	24	35	48	48	48	49	40	385
104	6	6	11	6	9	12	12	12	12	10	96
105	7	6	11	6	8	12	12	12	12	10	96
113	6	6	11	6	9	12	12	12	13	10	97
114	6	6	11	6	9	12	12	12	12	10	96
Grand Total	79	78	143	78	115	154	155	156	156	130	1244

4.2 Overall Trends

Descriptive statistics were used to show the FC distribution for the 13 stations over the 10 year time period as well as by shellfish growing classification areas (Figure 16 and Table 6). For the 10-year time period, the Approved classification stations showed the lowest FC concentration, and the Prohibited classification stations showed the highest concentration. Although our descriptive statistical methods are different than those used by DOH, the general trends are in agreement.

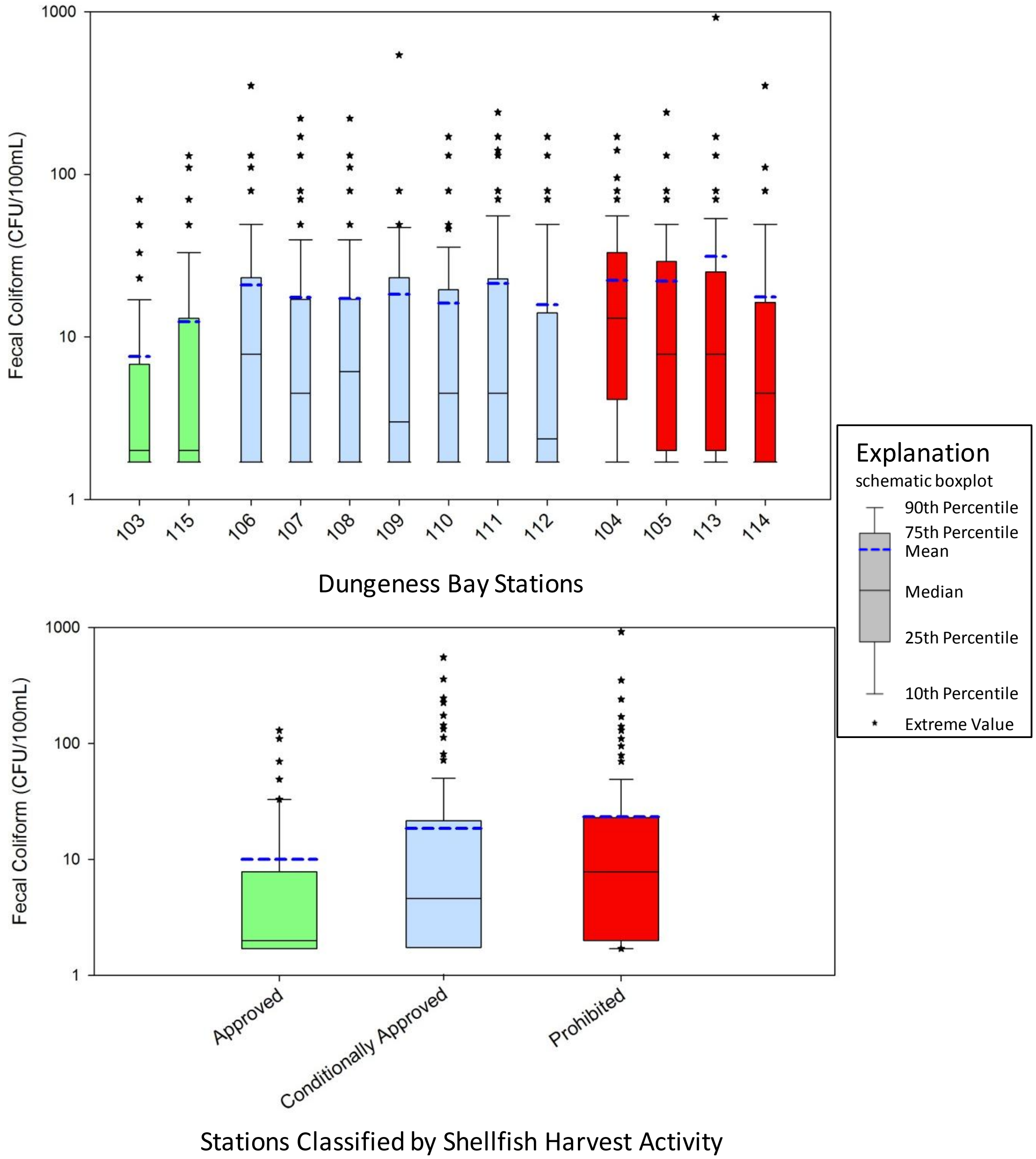


Figure 16. Box and Whisker Plot of Department of Health Marine Data Between 1999 and 2008 for Shellfish Growing Stations (upper) and Classified by Shellfish Harvest Growing Area (lower). Color Codes Represent Approved Areas (green), Conditionally Approved (blue), and Prohibited (red).

Table 6. Median, 25th, and 75th percentile of FC Concentrations (CFU/100 mL) Collected from Marine Monitoring Stations within the Dungeness Bay. [1]

Station Names	N	Median (25th and 75th Percentile)
Approved for Harvest	190	2.00 (1.70 - 7.80)
103	94	2.00 (1.70 - 6.80)
115	96	2.00 (1.70 – 13.0)
Conditionally Approved	669	4.50 (1.70 – 21.0)
106	96	7.80 (1.70 – 23.0)
107	95	4.50 (1.70 – 17.0)
108	95	6.10 (1.70 – 17.0)
109	96	3.00 (1.70 – 23.0)
110	97	4.50 (1.70 – 19.5)
111	96	4.50 (1.70 – 22.8)
112	94	2.35 (1.70 – 14.0)
Prohibited from Harvest	385	7.80 (2.00 – 23.0)
104	96	13.0 (4.13 – 33.0)
105	96	7.80 (2.00 – 29.0)
113	97	7.80 (2.00 – 25.0)
114	96	4.50 (1.70 – 16.3)

[1] Highlighted cells indicate the category and station with the greatest median concentration.

A generalized linear model was used to examine the variability in data and look at the effects of shellfish harvest category, year, season (i.e. wet, dry), and the harvest category by season interaction. The means of each harvest category depicted in Figure 17 suggest a continuous increase in concentration with each greater restriction in harvest. However, the significant interaction effect of harvest category by season (error d.f. 1229, $p < 0.001$) showed that the mean FC concentration of the Conditionally Approved was the lowest concentration of the three shellfish harvest categories during the dry season (2.9 CFU/100 mL with a 95% confidence interval of 2.5 to 3.3) and was the highest concentration over all categories during the wet season (13.9 CFU/100 mL with a 95% confidence interval of 12.3 to 15.8). Thus, the individual months were evaluated further in an expanded model.

Another generalized linear model was used to examine the effects of shellfish harvest category, individual stations, years, months and tidal stage (ebb and flood), and the consistency of each stations response over months and at each tidal stage (i.e., the interaction of station with month and station with tidal stage). The interaction of station with tidal stage was not significant (error d.f. = 1066; $p=0.79$) and was removed from the model. The interaction of station with month was significant, therefore each set of stations grouped by their shellfish harvest classification was analyzed individually as a function of station, year, month, tide and the interaction of station and month.

For the 2 stations categorized as Approved (stations 103 and 115) the interaction effect of station by month was not significant (error d.f. 156; $p = 0.2$). The main effects of year and tide (ebb and flood) were also not significant ($p > 0.37$); however, the main effect of month was significant ($p = 0.02$), and the effect of station was nearly significant ($p = 0.065$; Figure 18).

For the Conditionally Approved stations, the interaction effect of station by month was not significant (error d.f. 575; $p = 0.29$). The main effects of station and tide (ebb and flood) were not significant ($p > 0.25$). The main effect of month was significant ($p < 0.001$) and the effect of year was nearly significant (p = 0.07; Figure 18). Months associated with the dry season (April through September) tended to have lower LS-means.

For the Prohibited stations (stations 104, 105, 113, and 114), the interaction effect of station by month was not significant (error d.f. 327; p = 0.89). The main effects of year, month, and tide (ebb and flood) were significant (p < 0.02). The effect of stations was nearly significant (p = 0.056; Figure 18).

The Conditionally Approved harvest category allows harvest between February and October. A generalized linear model was used to analyze each harvest season separately using only the Conditionally Approved and Prohibited Harvest stations as a function of harvest category, year, tidal condition, and the interaction of category and year. For the November to January time period, only the main effects of harvest category and year were significant (error d.f. = 275; p < 0.007). The Conditionally Approved category had a greater LS-mean than the Prohibited Harvest category. The main effect of tide condition (ebb or flood) was not significant (p = 0.18). For the February to October time period, again only the main effects of harvest category and year were significant (error d.f. = 737; p < 0.001). This time, the Conditionally Approved category had a smaller LS-mean than the Prohibited Harvest category. The main effect of tide condition (ebb or flood) was again not significant (p = 0.41).

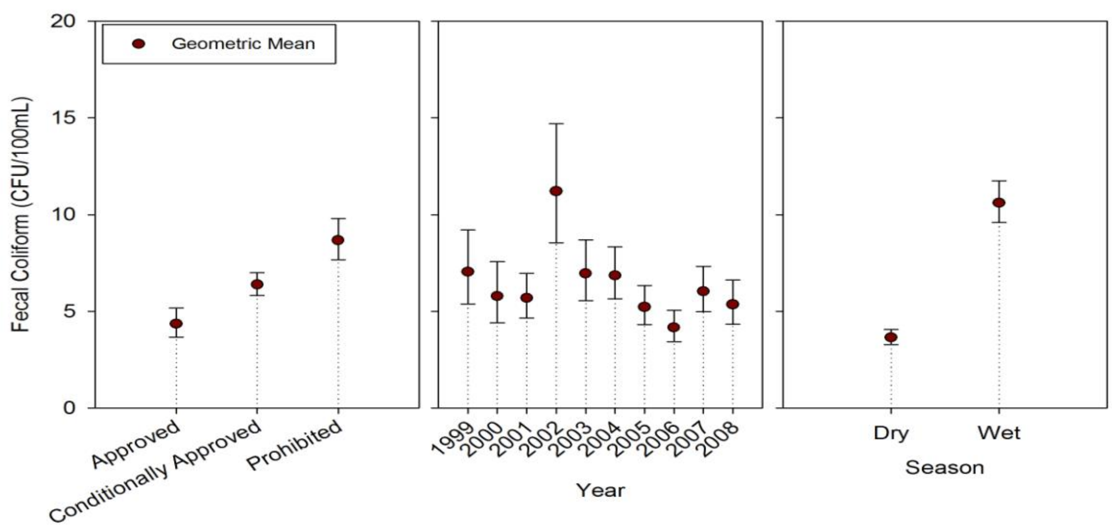


Figure 17. The Geometric Mean and 95% Confidence Interval of Fecal Coliform Concentration in Dungeness Bay by Shellfish Harvest Growing Area (left), Year (center) and Month (right) between 1999 and 2008.

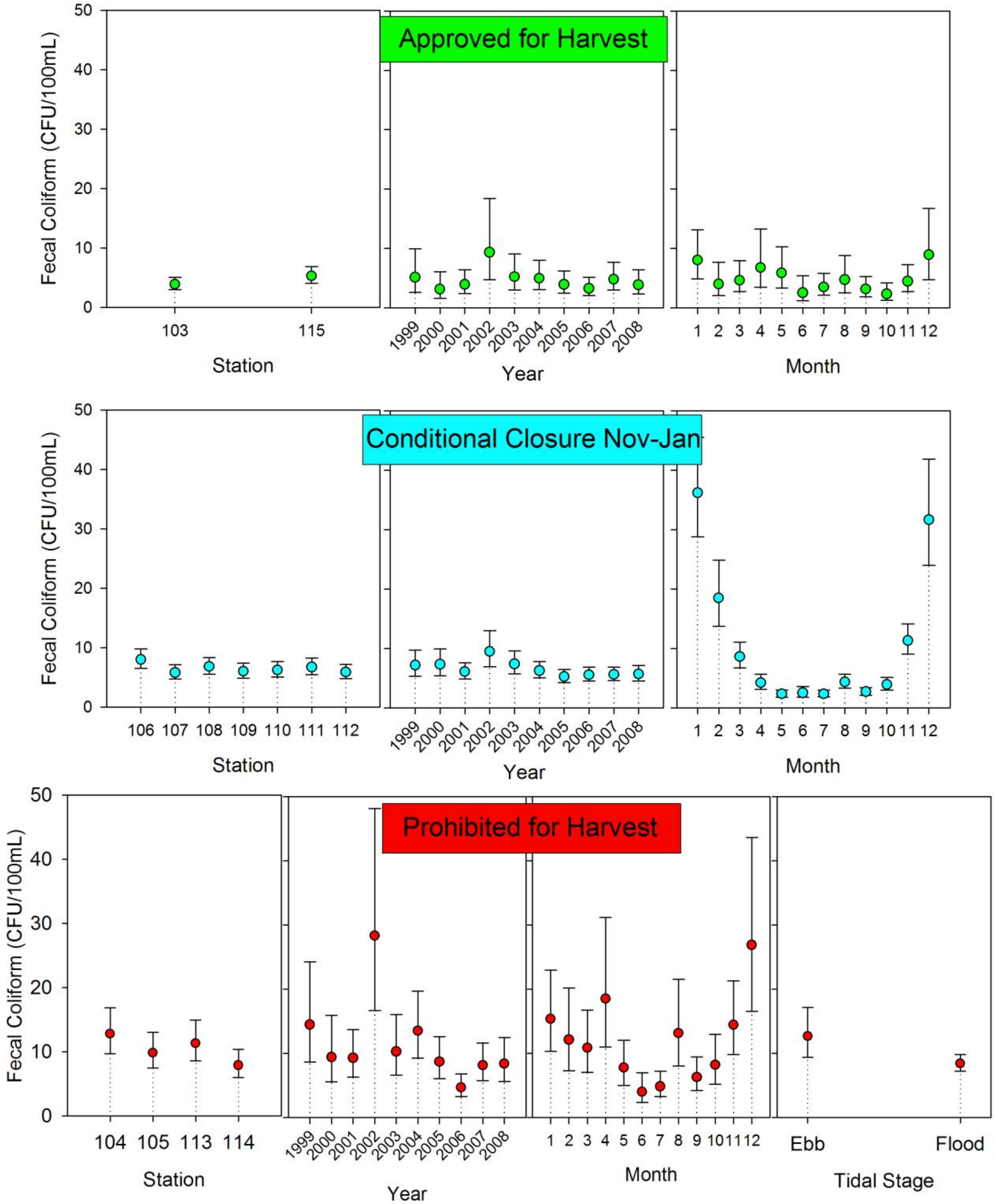


Figure 18. The Geometric Mean and 95 % Confidence Interval of Fecal Coliform Concentration for each Shellfish Harvest Growing Area by Station, Year, Month, and Tidal Stage between 1999 and 2008.

5.0 Effectiveness of Best Management Practices

5.1 Irrigation Piping Demonstration *(TWG Task 2d)*

5.1.1 Background

The Dungeness Watershed contains an extensive irrigation system. Due to its location in the rainshadow of the Olympic Mountains, the Dungeness Valley experiences very low precipitation. In 1896, settlers began diverting water from the Dungeness River into open ditches to irrigate the arid Sequim Prairie. Over the next several decades, approximately 173 miles of canals, ditches and pipelines were constructed to distribute irrigation water throughout the valley (CIDMP, 2006). Flood irrigation was used to irrigate the land until technological advancements allowed pumping and sprinklers beginning after World War II. Flood irrigation is no longer allowed in the valley and many open ditches have been replaced with pipelines.

Piping irrigation ditches is a best management practice for water conservation by preventing conveyance losses (i.e. water losses to seepage and evapotranspiration). Furthermore, because the water conveyance system is enclosed in a pipe, contaminants no longer enter the water (Joe Holtrop, personal communication, 2008). Additionally, if a pipeline is close-ended, there is no spilling of excess water ("tailwater") at the end of the distribution system, thereby eliminating conveyance of contaminants at the downstream end of the irrigation system. With a completely closed system, no river water enters the pipeline unless water is taken out somewhere downstream for irrigation or stock watering, thereby eliminating both conveyance losses and tailwaters. Piping also reduces irrigation ditch maintenance since ditches no longer need to be cleared of vegetation, debris and sediment. Delivery of water to irrigators can be more efficiently managed with a piped system. Further, a closed system can generate sufficient head pressure in the pipeline to eliminate the need for pumps to apply irrigation water, particularly for users lower in the system.

By contrast, with open ended pipelines or ditches, there needs to be a small reservoir at the end, in order for the last users on the distribution laterals to have enough water to keep their pumps from running dry and burning out. Even with a small reservoir at or near the end of the ditch system, surplus irrigation flows not withdrawn from the ditch must be accommodated. These surplus flows, which typically return the excess irrigation water to a stream, or Dungeness Bay or the Strait of Juan de Fuca in our study area, are known as "tailwater". If the irrigation water has picked up contaminants along the open route, these are likely to also enter the receiving waters at the end.

5.1.2 Piping for TWG project

The Clallam Ditch Company (Company), Dungeness Irrigation Group (Group) and the Cline Irrigation District (District) supply irrigation water from the Dungeness River to approximately 1,500 acres of land in the lower watershed on the west side of the Dungeness River (HDR, 2006). The Company is a private entity, delivering water to the Carlsborg area west of Sequim. The District is a public entity, delivering water to the north of the land served by the Company. The Group is a private entity that shares the river withdrawal infrastructure and a fish screen with the Company and District, then splits off to supply irrigation water to the area west of the Company and District. Prior to the project, the Company and District main canals crossed each other several times which was inefficient, both economically and in terms of water loss. In part, the TWG irrigation BMP demonstration under *Task 2d* has helped unite the District with the Company, in a joint public-private partnership project to replace the two independent main irrigation canals with one pipeline. This demonstration is the first public-private partnership of its kind in the Dungeness Valley, and it exemplifies the types of measures proposed in the Comprehensive Irrigation District Management Plan (2006), which addresses both the Clean Water Act and the Endangered Species Act. The irrigation ditch and piping system for the Clallam-Cline Combo project are shown in Figures 19 and 20. Included on these maps are the dates when various sections of ditch were piped, and when "shut off" dates (i.e. no tailwaters) were implemented. Funding from the TWG project contributed to the piping of several significant sections, including elimination of tailwaters into Dungeness Bay (Figure 19) and a section in the southern portion of the system (Figure 20).

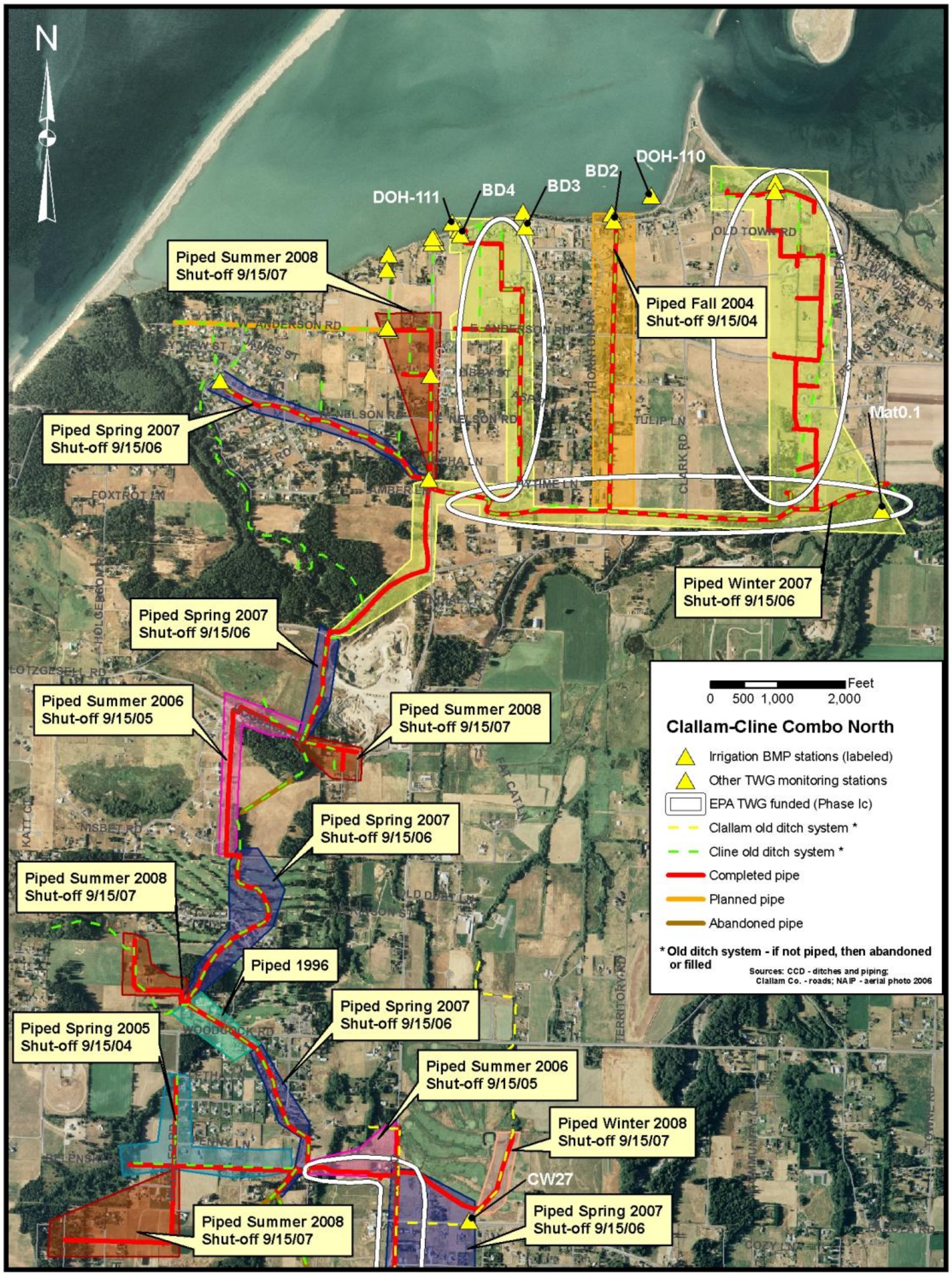


Figure 19. The Clallam-Cline Combo irrigation System Showing the Northern Extent of the Ditches and a Timeline of Piping History. Areas circled in white received funding from the EPA TWG project.

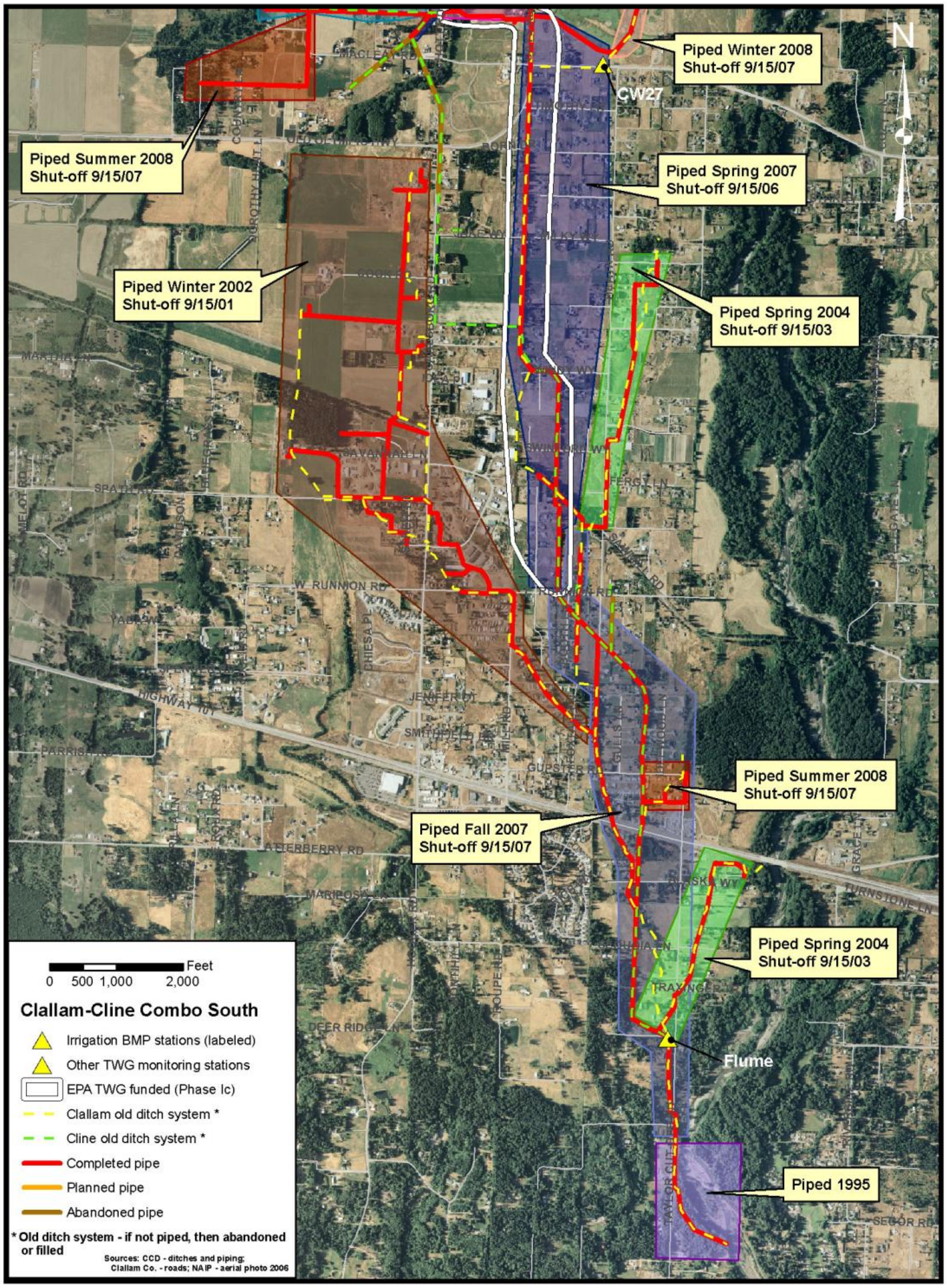


Figure 20. The Clallam-Cline Combo irrigation System Showing the Southern Extent of the Ditches and a Timeline of Piping History. Areas circled in white received funding from the EPA TWG project.

5.1.3 Monitoring and Effectiveness Analysis

Since the early 1990's, the Clallam Conservation District has identified and monitored FC in nearly all irrigation tailwater ditches in order to identify water pollution sources and prioritize remediation such as piping projects. Most tailwater ditches exceeded state standards for FC bacteria (Joe Holtrop, personal communication, 2008). Monitoring irrigation piping for effectiveness of bacterial contamination reduction is challenging in the sense that although monitoring before construction is possible, monitoring post-construction is difficult if the piping occurs as planned, since irrigation tailwater (i.e. downstream) is eliminated, and hence there is nothing to monitor. The TWG Workplan (2004) included monitoring sites as part of the Irrigation Ditch Piping BMP, including the "Flume" site (Figures 4 and 20) and "CW27" (Figures 3 and 19). In addition, several sites that emptied into Dungeness Bay (Bluff Ditch sites – Figures 1 and 3) were monitored as part of the TWG Initiative. Most of these sites were considered tailwaters of irrigation ditches.

There were very few bluff ditch irrigation sites (IRR-1 through 7) that were sampled at a frequency to allow statistical comparisons before and after planned piping projects. Although these stations were sampled during the TWG Initiative (Table 2), unlike many other monitoring stations, they were not sampled routinely before piping occurred, and since they were frequently dry, they were only sampled intermittently. The station sampled most often prior to piping was IRR-3, which is considered a tailwater for the irrigation ditch (Figure 19, Table 2). Figure 21 shows a plot of FC concentrations at upstream stations (Flume and CW27) on the Clallam Cline Irrigation project as well as IRR-3 (downstream station). The upstream stations were only sampled five times during TWG monitoring because the water was shut off (9/15/06) and the ditch was piped. IRR-3, a tailwater for this piping project had been monitored since 2004 on a frequent basis. In some areas where piping has occurred, a stormwater conveyance ditch had to be reconstructed above or next to the irrigation piping (per Clallam County Road Department regulations) to continue to convey storm runoff water. This was the case for IRR-3, hence samples were collected after the piping from this direct discharge into Dungeness Bay. Figure 21 (top) shows that even after piping of the irrigation conveyance, the FC concentration, although highly variable as it was before the piping, was not significantly different (error d.f. = 26; $p = 0.30$) than before the piping, after correction for the seasonal variability. In this figure, Bluff Ditch 3 includes the combined BD-3 and NSD-3 stations (IRR-3). It should be noted that the potential source of contamination to this storm water runoff ditch is a much smaller area than prior to piping when several miles of open irrigation ditch led to this discharge location.

An additional approach was used to examine the impact of piping on tailwater discharge into Dungeness Bay by comparing data before and after the piping at the DOH marine sites located near the Bluff ditch sites (DOH Stations 110, 111, and 112). As an example, Figure 21 (bottom) shows the FC concentration measured at Bluff Ditch-3 (IRR-3) and the nearby marine DOH Station 110. A generalized linear model with the main effects of season, and pre- or post-piping and their interaction was used to examine the FC concentrations at each of the stations. The DOH station 110 showed a statistically significant difference between pre- and post-piping ($p = 0.05$), with a geometric mean (corrected for season) before the piping of 7 CFU/100 mL and 4 CFU/100 mL after the piping. However these concentrations are so low, that the difference is not meaningful from a water quality perspective. The mean FC concentrations at Stations 111 and 112 were not significantly different before and after irrigation piping (error d.f. = 83 and 108 respectively, $p > 0.16$).

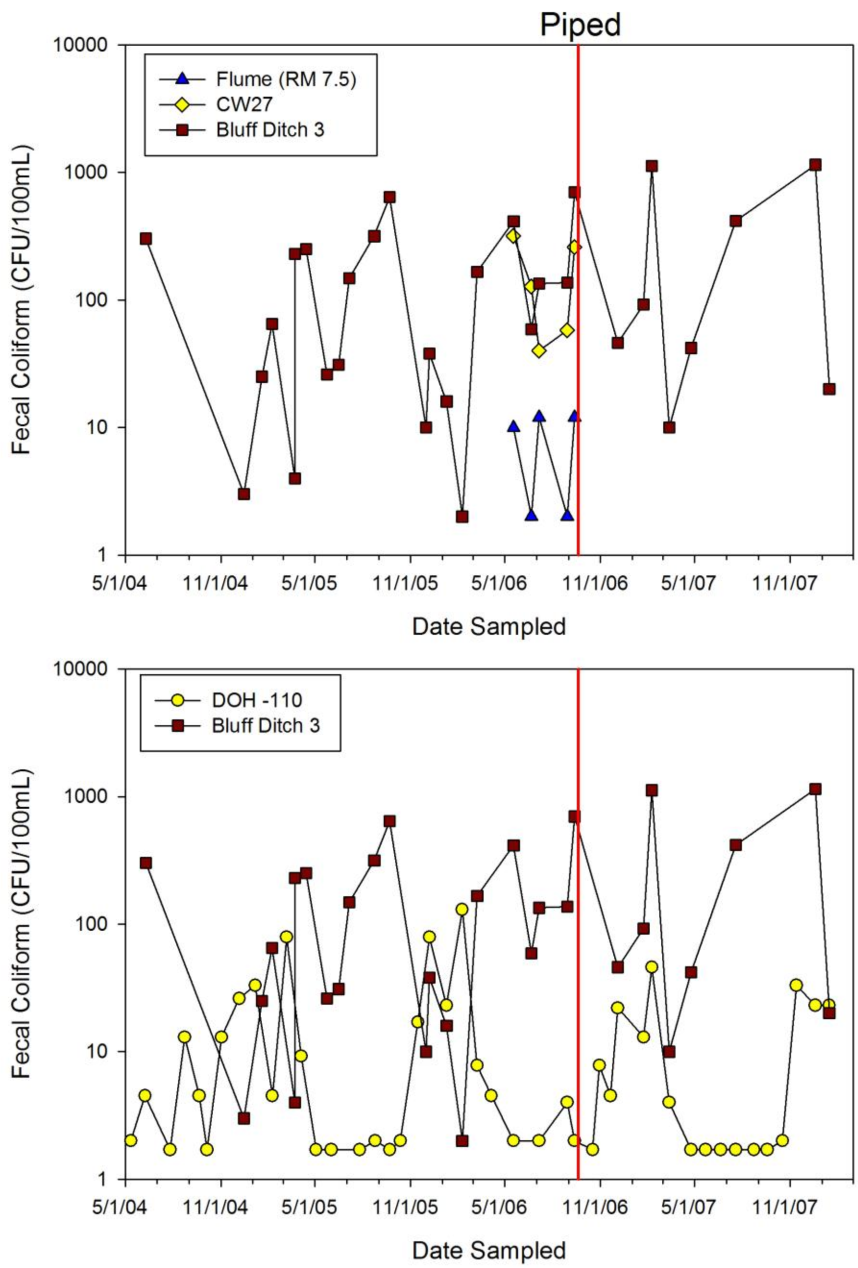


Figure 21. Fecal Coliform Concentrations at Selected Stations Included in the Irrigation Piping Effectiveness Monitoring Analysis.

5.2 Homeowner Septic System Repairs *(TWG Task 2b)*

5.2.1 Background

Failing septic systems have been identified as one of a number of potential sources contributing to FC concentrations found in the Dungeness Watershed. Under the TWG Initiative, septic repairs have been identified as a BMP that could reduce the impact of FC pollution in the watershed. Under Task 2b *(Homeowner Sewage Management BMP Education and Training)* of the TWG Initiative, three elements were addressed: i) education and cost-share incentives for homeowners to inspect, upgrade or replace failing septic systems, ii) O&M Maintenance Agreement facilitation and training to industry professionals on alternative sewage managements systems, and iii) development of a market-based incentive guide for homeowners to guide decisions about septic management alternatives. Since October 2004, 53 septic repairs or upgrades were completed under Task 2b. These repairs included eight properties on the County's septic of concern (SOC) list, with the remaining properties located along water bodies (shoreline, river, streams, ditches) that had the potential of impacting Dungeness Bay. Nine of the repairs were considered direct discharges into surface water bodies such as a ditch, creek, river or Bay.

5.2.2 Monitoring and Effectiveness Analysis

The locations of the SOC repairs are shown in Figure 22. In order to examine the effectiveness of FC reduction to nearby waters, the nearest upstream and downstream TWG and DOH monitoring stations were located for each SOC. In some cases, two upstream or downstream stations were examined, and in other cases an upstream station did not exist. Table 7 lists the upstream and downstream stations used in analysis of the data, as well as the date of the septic repair, and number of FC observations used in the analysis. An additional site was examined (SOC #1) that was repaired prior to the TWG Initiative. This was included primarily because a longer temporal FC dataset existed upstream and downstream of this site.

In general, for almost all septic repair sites, there wasn't a significant difference between upstream and downstream FC levels, based on the nearest TWG monitoring site, or a significant difference before or after the septic repair at those monitoring sites (Table 7). An example is shown in Figure 23. In this case the difference in FC concentrations at MAT3.4 and MAT3.7 before and after a septic repair on 5/1/2006 was not significant ($p = 0.46$). Figure 24 shows a nearby site in Dungeness Bay (DOH 113) before and after the septic repair. In this case the effect of time (before and after the repair) was nearly significant ($p=0.09$), however the variability in concentration over time is very high. Although the analysis would indicate there is very little difference in FC concentrations based on these septic repairs, a statistically rigorous sampling design was not implemented to examine the question. Rather, the nearest available monitoring site was selected which in some cases was 0.25 to 0.5 miles away.

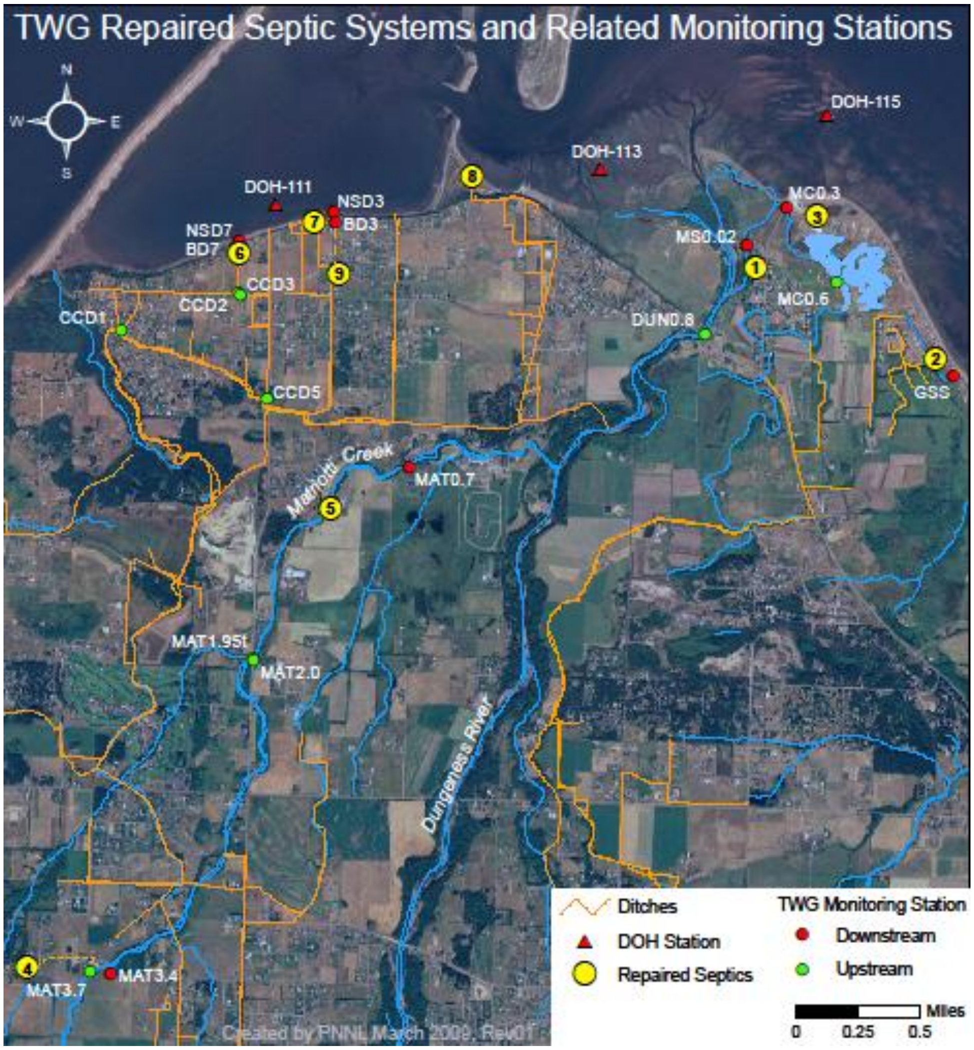


Figure 22. Map of Septic Systems Repaired or Upgraded during TWG, with Monitoring Stations Used in Effectiveness Analysis.

Table 7. TWG and DOH Monitoring Stations Evaluated for FC to Determine the Effectiveness of Septic Repairs. Differences between downstream and upstream observations (downstream minus upstream) are calculated only when they occur on the same date.

Septic of Concern and Repair Date	Upstream Monitoring Stations Mean and 95% CI	Downstream Monitoring Stations Mean and 95% CI	Statistical Results on Differences in FC Concentrations Before and After Repair
#1 8/08/2001	**Dun0.8** 14.1 CFU/100 mL (8.48 to 19.7)	**MS0.02** (no data before repair from any downstream sites) 219 CFU/100 mL (96.6 to 342)	• Kruskal-Wallis test between seasons (Wet and Dry) not significantly different, $p = 0.84$ • One-sample t-test of mean difference equal to 0; significantly greater than 0, $p = 0.002$ • Mean Difference = 205 CFU/100 mL (84 to 326) • n = 22 differences between 2006 and 2008
#2 11/05/2006	NA	**GSS** Before:145 CFU/100 mL (65.3 to 225) After: 137 CFU/100 mL (7.37 to 266)	• Generalized Linear Model with seasons (Wet and Dry), time (Before and After), and the interaction of season by time; no effects were significant, $p > 0.68$ • Before n = 44 between 1999 and 2006 After n = 15 between 2006 and 2008
#3 6/28/2006	**MC0.6** Before:46.2 CFU/100 mL (25.9 to 66.4) After: 112 CFU/100 mL (41.4 to 182)	**DOH 115** 11.9 CFU/100 mL (7.66 to 16.2) **MC0.3** Before:66.2 CFU/100 mL (35.2 to 97.2) After: 86.9 CFU/100 mL (25.4 to 148)	• Kruskal-Wallis test on DOH 115 by time (Before and After) not significantly different, $p = 0.90$, n = 87 between 1999 and 2008 • Kruskal-Wallis test on differences (MC0.3 minus MC0.6) Before and After repair; not significant, $p = 0.11$ • Before n = 25 differences between 2004 and 2006 After n = 19 differences between 2006 and 2008
#4 5/01/2006	**Mat3.7** Before:43.7 CFU/100 mL (0 to 90.5) After: 61.5 CFU/100 mL (35.3 to 87.8)	**Mat3.4** Before:67.5 CFU/100 mL (27.9 to 107) After: 67.4 CFU/100 mL (39.3 to 95.5)	• Kruskal-Wallis test on differences Before and After repair; not significant, $p = 0.46$ • Before n = 18 differences between 2004 and 2006 After n = 21 differences between 2006 and 2008
#5 5/18/2006	**Mat1.97t** (Mat2.0 from 8/23/2005 to 2008) Before:233 CFU/100 mL (143 to 324) After: 104 CFU/100 mL (45.8 to 163)	**Mat0.7** Before:95.1 CFU/100 mL (56.8 to 133) After: 58.1 CFU/100 mL (29.8 to 86.4)	• Kruskal-Wallis test on differences Before and After repair; not significant, $p = 0.17$ • Before n = 66 differences between 1999 and 2006 After n = 20 differences between 2006 and 2008
#6 5/26/2006	**CCD3** Before:92 CFU/100 mL (0 to 215) After: 4 CFU/100 mL	**BD7 and NSD7** Before:24 CFU/100 mL (0 to 66) After: 54 CFU/100 mL	Not enough Data • Before n = 5 differences between Feb. and Aug. 2005 After n = 1 difference on 7/6/2006
#7 2/08/2005	NA	**DOH 111** Before:17.0 CFU/100 mL (9.10 to 25.0) After: 27.4 CFU/100 mL (10.6 to 44.2)	• Kruskal-Wallis test on FC Before and After repair; not significant, $p = 0.89$ • Before n = 57 differences between 1999 and 2005 After n = 39 differences between 2005 and 2008
#8 10/22/2004	NA	**DOH 113** Before:25.5 CFU/100 mL (16.3 to 34.8) After: 36.4 CFU/100 mL (0 to 73.7)	• Kruskal-Wallis test on FC Before and After repair; not significant, $p = 0.09$ • Before n = 47 differences between 1999 and 2004 After n = 50 differences between 2004 and 2008
#9 8/30/2007	**CCD1** Before:114 CFU/100 mL (19.1 to 209) After: NA	**BD3 and NSD3** Before:194 CFU/100 mL (92.6 to 296) After: 584 CFU/100 mL	Not enough Data • Before n = 10 differences between 2005 and 2006 After n = 0 difference

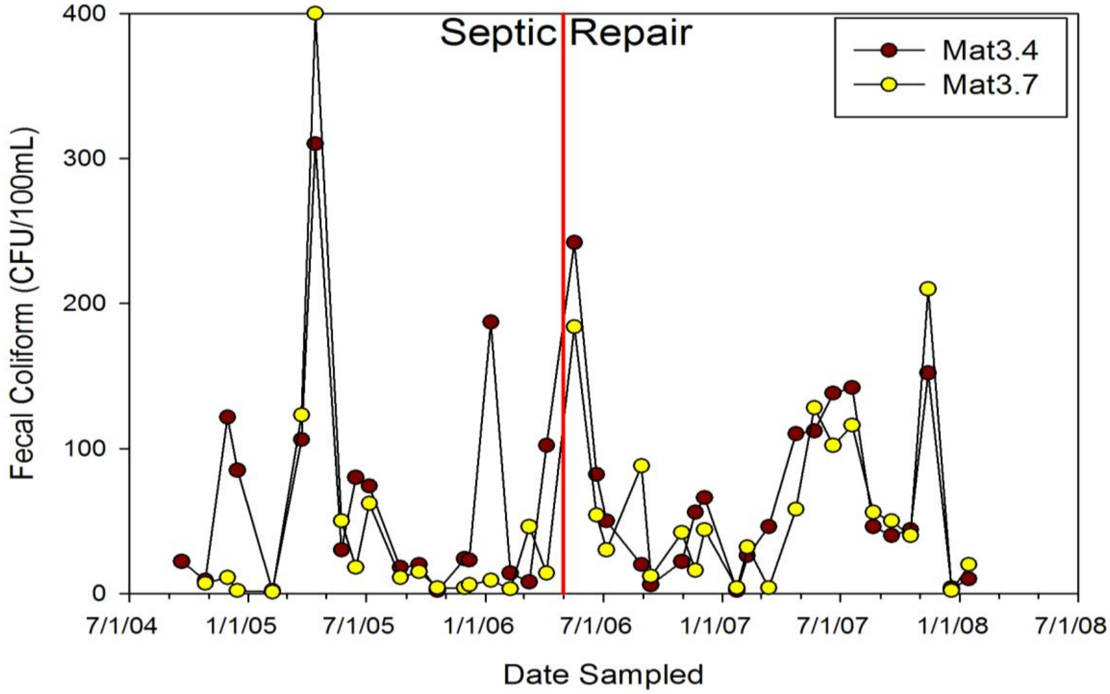


Figure 23. Fecal Coliform Concentration Upstream (MAT3.7) and Downstream (MAT3.4) of a Septic Repair (SOC #4) and Before and After the Repair (vertical red line).

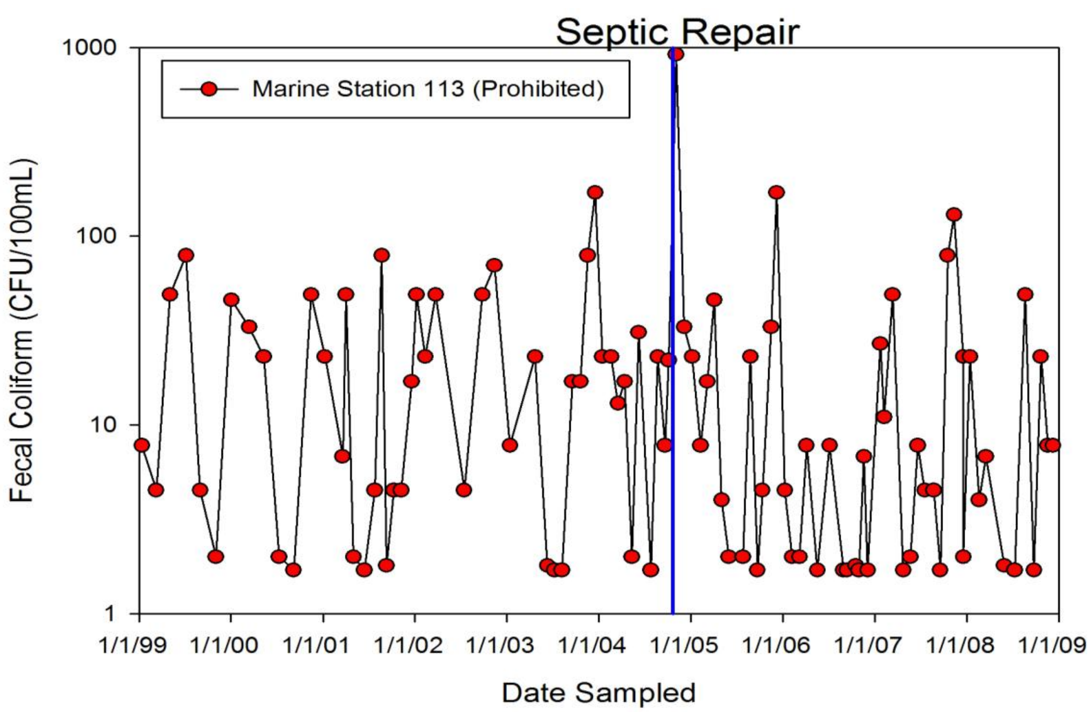


Figure 24. Fecal Coliform Concentration Upstream Before and After a Septic Repair (vertical blue line) at a Nearby Monitoring Station (DOH 113).

6.0 Nutrient Characterization in the Watershed

6.1 Background

Nutrients (primarily nitrogen and phosphorous) are essential elements in all aquatic ecosystems and are needed for plants and animals to survive and grow. The various forms of nitrogen and phosphorus are also the primary nutrients of interest in water quality investigations, including nitrate, nitrite, ammonia, and phosphate. When found in low concentrations, various forms of nitrogen and phosphorus can act as tracers of potential sources of contaminants from sources upstream or in groundwater, depending on their speciation. However, when these nutrients are found at excessive levels, they can have a negative impact on aquatic systems. Anthropogenic alterations within a watershed generally lead to higher nutrient concentrations resulting from both point and non-point source discharges (Omernik 1976). Common sources of nutrients include leaf litter and yard waste, agricultural and irrigation processes, chemical fertilizers, landscaped areas, and gardens. In addition, high nutrient concentrations can originate from failing septic systems or from inadequate treatment of wastewater discharges from urban waste-water treatment plants, and atmospheric deposition, including snowmelt runoff, of nutrient compounds from automobile emission, industrial facilities, and power generation plants (Oberts 1994). Soil erosion can also be a significant source and pathway for the mobilization of nutrients as they tend to be found in particulate form. Individual nutrient parameters are affected by chemical and biological processes that can change their speciation or form and can also transfer them to or from water, soil, biological organisms, and the atmosphere. The chemical speciation of nutrients becomes an important factor both for evaluation of both ecological impacts and as a tracer of source contaminants.

Many studies have linked nutrient levels in runoff to contributing drainage area land-uses, with agricultural and urban areas producing the highest concentrations (Chessman et al. 1992; Wernick et al. 1998; USGS 1999). Residential lawns and turf areas (e.g. sports fields, golf courses, and parks) in urbanizing watersheds have been identified as "hot spots" for nutrient input into urban runoff . In general, lawns and turf areas contribute greater quantities of nutrients than other urban source areas. Research suggests that nutrient concentrations in runoff from lawns and turf areas can be as much as four times greater than those from other urban nutrient sources (Bannerman et al. 1993; Waschbusch et al. 2000).

Anthropogenic nitrogen is typically found as inorganic forms of nitrogen: nitrate anion or ammonium. Nitrates are present in fertilizers, human wastewater, and animal wastes. The nitrate anion is not usually adsorbed by soil and therefore moves with infiltrating water. Nitrate contamination of groundwater can be a serious problem, resulting in contamination of drinking water supplies and potential human health risks at elevated levels.

The forms of nitrogen that are of particular interest as both tracers and contaminants are the dissolved nitrogen species, such as ammonia (referred to in this report as NH_4), nitrate (NO_3), and nitrite (NO_2). These compounds are collectively referred to as total inorganic nitrogen (TIN). Nitrate is highly soluble in oxygenated water and stable over a wide range of environmental conditions allowing it to be readily transported in ground water and streams. On the other hand ammonia is soluble in natural water, but generally not stable as it is readily oxidized to nitrite and then nitrate in freshwaters containing oxygen, or alternatively, transformed to nitrogen gas in water that is low in oxygen. Due to the instability of nitrite, many studies report only the sum of nitrate and nitrite. In this report, the sum is referred to as NO3-2 and represents both calculated (a majority of this data set quantified both species) and directly measured for data reported from the Washington Department of Ecology Total Maximum Daily Load (TMDL) program.

Phosphates (referred to as PO_4), including orthophosphate, are the most significant forms of dissolved phosphorus in natural water. They are only moderately soluble and tend to adhere to soil particles resulting in the retention of phosphorus by soils and limited mobility in ground water. However, erosion can transport considerable amounts of phosphate-laden particulates through watersheds and become a source of excess nutrient in disturbed or built environments.

Phosphate is the key form of phosphorus found in non-point source runoff. Phosphate exists in runoff as either soluble reactive phosphorus (SRP) or orthophosphates, poly-phosphates, and as organically bound phosphate. Due to the reactivity of SRP, studies generally collect total phosphorus (TP). In this study, both TP and total phosphates (PO_4) were quantified. Natural forms of organophosphates are present in marine and fresh water systems but anthropogenic sources such as poly-phosphates in detergents, orthophosphates in sewage and septic systems, and inorganic phosphates from degraded phosphorous-based pesticides and herbicides can overwhelm natural levels.

For this study, the approach taken with the nutrient data was similar to FC data, with the exception that far fewer nutrient observations were available for analysis. However descriptive statistics are reported in addition to a trends analysis of the data based on regression models. Correlations between nutrient data and FC data are also examined as well as correlations with rainfall.

6.2 Descriptive Statistics

Water quality samples for nutrient analysis were collected during the TWG study between 2005 and 2008. In addition, some data was collected as part of the Dungeness River TMDL during 1999 and 2000 (Sargeant 2002), however that nutrient data was not analyzed at that time. There were a total of 831 observations of nutrient data collected from the Dungeness River and tributaries (Table 8) and 158 observations of nutrient data collected from irrigation ditches and other fresh water sampling stations within the Dungeness watershed (Table 9 and 10). Matriotti Creek accounted for the greatest number of nutrient observations (n = 285) followed by Bell Creek (n = 176). There were 74 nutrient observations collected from the Flume stations and 49 observations collected from the bluff ditch stations.

Table 8. Numbers of Nutrient Observations (i.e. NH_4, NO_3, $N0_2$, TN, TP, PO_4, TIN) between 2005 and 2008 for Dungeness River and Tributary/Creek Stations.

River/Tributary	Number of Samples						
	PO4 (mg/L)	NO3(mg/L)	NO2(mg/L)	NH4(mg/L)	TP(mg/L)	TN(mg/L)	TIN
Bell Creek	175	176	176	176	142	136	176
2005	21	22	22	22			22
2006	70	70	70	70	58	58	70
2007	77	77	77	77	77	71	77
2008	7	7	7	7	7	7	7
Dungeness River	162	124	126	162	136	129	162
1999	6			6	6	6	6
2000	30			30	30	27	30
2005	16	14	16	16			16
2006	55	55	55	55	46	46	55
2007	51	51	51	51	50	46	51
2008	4	4	4	4	4	4	4
Johnson Creek	29	29	29	29	22	21	29
2005	4	4	4	4			4
2006	12	12	12	12	9	9	12
2007	12	12	12	12	12	11	12
2008	1	1	1	1	1	1	1
Matriotti Creek	285	267	267	284	214	203	285
1999	3			3	3	3	3
2000	19	4	4	19	15	15	19
2005	47	47	47	46			47
2006	105	105	105	105	85	84	105
2007	103	103	103	103	103	93	103
2008	8	8	8	8	8	8	8
Meadowbrook Creek	122	104	104	121	100	96	122
1999	3			3	3	3	3
2000	15			15	15	15	15
2005	15	15	15	14			15
2006	42	42	42	42	35	35	42
2007	43	43	43	43	43	39	43
2008	4	4	4	4	4	4	4
Meadowbrook Slough	57	39	39	57	50	48	57
1999	3			3	3	3	3
2000	15			15	15	15	15
2005	5	5	5	5			5
2006	12	12	12	12	10	10	12
2007	20	20	20	20	20	18	20
2008	2	2	2	2	2	2	2
Grand Total	830	739	741	829	664	633	831

Table 9. Numbers of Nutrient Observations between 2005 and 2008 for the Irrigation Ditches and Golden Sands Slough.

Station Names	PO4 (mg/L)	NO3(mg/L)	NO2(mg/L)	NH4(mg/L)	TP(mg/L)	TN(mg/L)	TIN
CW27	5	5	5	5	5	5	5
2006	5	5	5	5	5	5	5
Flume	74	74	74	74	64	62	74
CCD1	6	6	6	6	5	5	6
2005	1	1	1	1			1
2006	5	5	5	5	5	5	5
CCD2	6	6	6	6	3	3	6
2005	1	1	1	1			1
2006	4	4	4	4	2	2	4
2007	1	1	1	1	1	1	1
CCD3	9	9	9	9	6	6	9
2005	2	2	2	2			2
2006	5	5	5	5	4	4	5
2007	2	2	2	2	2	2	2
CCD4	5	5	5	5	4	4	5
2005	1	1	1	1			1
2006	3	3	3	3	3	3	3
2007	1	1	1	1	1	1	1
CCD5	6	6	6	6	6	6	6
2005	1	1	1	1			1
2006	4	4	4	4	5	5	4
2007	1	1	1	1	1	1	1
CCD14	11	11	11	11	11	11	11
2006	1	1	1	1	1	1	1
2007	9	9	9	9	9	9	9
2008	1	1	1	1	1	1	1
CCD15	12	12	12	12	12	11	12
2006	2	2	2	2	2	2	2
2007	9	9	9	9	9	8	9
2008	1	1	1	1	1	1	1
CCD16	14	14	14	14	13	12	14
2006	2	2	2	2	1	1	2
2007	11	11	11	11	11	10	11
2008	1	1	1	1	1	1	1
Flume RM7.5	5	5	5	5	4	4	5
2006	5	5	5	5	4	4	5
Golden Sands Slough GSS	30	30	30	30	23	22	30
2005	5	5	5	5			5
2006	12	12	12	12	10	10	12
2007	12	12	12	12	12	11	12
2008	1	1	1	1	1	1	1

Table 10. Numbers of Nutrient Observations between 2005 and 2008 for the Bluff Ditch Stations

Station Names	PO4 (mg/L)	NO3(mg/L)	NO2(mg/L)	NH4(mg/L)	TP(mg/L)	TN(mg/L)	TIN
Irrigation-1	1	1	1	1			1
BD1	1	1	1	1			1
2005	1	1	1	1			1
Irrigation-3	20	20	20	20	14	14	20
BD3	16	16	16	16	12	12	16
2005	2	2	2	2			2
2006	7	7	7	7	5	5	7
2007	6	6	6	6	6	6	6
2008	1	1	1	1	1	1	1
NSD3	4	4	4	4	2	2	4
2005	2	2	2	2			2
2006	2	2	2	2	2	2	2
Irrigation-4	4	4	4	4	4	4	4
BD4	4	4	4	4	4	4	4
2007	4	4	4	4	4	4	4
Irrigation-5	10	10	10	10	9	9	10
BD5	5	5	5	5	5	5	5
2006	1	1	1	1	1	1	1
2007	4	4	4	4	4	4	4
NSD5	5	5	5	5	4	4	5
2005	1	1	1	1			1
2006	4	4	4	4	4	4	4
Irrigation-6	3	3	3	3	3	3	3
BD6	2	2	2	2	2	2	2
2007	2	2	2	2	2	2	2
NSD6	1	1	1	1	1	1	1
2006	1	1	1	1	1	1	1
Irrigation-7	11	11	11	11	10	10	11
BD7	9	9	9	9	9	9	9
2006	5	5	5	5	5	5	5
2007	4	4	4	4	4	4	4
NSD7	2	2	2	2	1	1	2
2005	1	1	1	1			1
2006	1	1	1	1	1	1	1
Grand Total	158	158	158	158	132	129	158

All years of available data were used to examine the correlation of nutrient data with FC concentration, rainfall, and each pair-wise nutrient calculated using all of the data collected from rivers, tributaries, and irrigation ditches within the Dungeness watershed (minimum n = 731; Table 11). Nutrients were not correlated with FC concentrations (correlation coefficient ranged from -0.06 to 0.3) or rainfall (correlation coefficient ranged from -0.01 to 0.09). The nutrients PO_4, NH_4, TP, and TN were highly correlated (correlation coefficient ranged from 0.73 to 0.91) to each other (Table 12). In addition, nitrate+nitrite (NO3-2) was correlated to TIN.

Table 11. Correlation Coefficients Between FC and Nutrient Concentrations and Rainfall Using Data Collected from Rivers, Tributaries, and Irrigation Ditches (pairwise comparison n = 731).

Correlation	Rainfall (inches)	PO_4 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	NH_4 (mg/L)	TP (mg/L)	TN (mg/L)	TIN (mg/L)
FC	-0.08	0.30	0.08	0.23	0.27	0.24	0.21	0.20
Rainfall (inches)	1.00	-0.01	0.07	-0.01	0.01	0.00	0.01	0.06

Table 12. Correlation Coefficients Between Nutrients Concentrations Using Data Collected from Rivers, Tributaries, and Irrigation Ditches (pairwise comparison n = 731).

Correlation	NO_3 (mg/L)	NO_2 (mg/L)	NO_3+NO_2 (mg/L)	NH_4 (mg/L)	TP (mg/L)	TN (mg/L)	TIN (mg/L)
PO_4 (mg/L)	0.23	0.63	0.25	0.73	0.91	0.76	0.54
NO_3 (mg/L)	1.00	0.40	1.00	0.08	0.23	0.44	0.90
NO_2 (mg/L)		1.00	0.42	0.34	0.50	0.49	0.51
NO_3+NO_2 (mg/L)			1.00	0.09	0.24	0.46	0.90
NH_4 (mg/L)				1.00	0.81	0.83	0.51
TP (mg/L)					1.00	0.87	0.63
TN (mg/L)						1.00	0.81
TIN (mg/L)							1.00

The median and 25th and 75th percentile of the nutrient concentrations for all data collected from rivers and tributaries was used to characterize the fresh water sources from 1999 to the present (Table 13). Concentration ranges for FC are provided in Table 13 as well, using the same subset of sampling dates for which nutrients were collected. In general, Bell Creek had the greatest concentrations of PO_4, TP, and TN. Matriotti Creek had the greatest concentrations of NO_3, NO_2, and TIN, and Meadowbrook Slough had the greatest concentrations of NH_4 and FC. For the irrigation ditches and other freshwater stations, data was available only from the TWG study time period, 2005 through 2008. The median and 25^{th} and 75^{th} percentile for all data collected during this time period is shown in Table 14. The bluff ditch stations had the greatest concentrations of PO_4, NO_3, NO_2, NO3-2, TP, TN, and TIN, while GSS had the greatest concentration of PO_4 and NH_4 (Table 13). Table 15 shows the nutrient concentrations for the two Dungeness Bay stations (DOH-108 and DOH113) with a marine influence. Although less data was collected for these stations, the concentrations are generally a little higher than the stations at the mouth of the Dungeness River.

Table 13. Median, 25th, and 75th Percentiles (in parentheses) of the Concentration of Each Nutrient and FC Concentration in Rivers and Tributaries Collected Concurrently from 1999 to 2008. [1]

Parameter	Bell Creek	Dungeness River	Johnson Creek	Matriott Creek	MDSL	Meadowbrook Creek
	n = 175	n = 162	n = 29	n = 285	n = 57	n = 122
PO_4 (mg/L)	0.052 (0.035 - 0.086)	0.005 (0.002 - 0.007)	0.038 (0.031 - 0.046)	0.024 (0.018 - 0.031)	0.017 (0.009 - 0.026)	0.014 (0.011 - 0.020)
NO_3 (mg/L)	0.153 (0.037 - 0.896)	0.042 (0.016 - 0.063)	0.132 (0.061 - 0.219)	0.890 (0.481 - 1.180)	0.058 (0.045 - 0.087)	0.151 (0.060 - 0.258)
NO_2 (mg/L)	0.002 (0.001 - 0.006)	0.000 (0.000 - 0.001)	0.001 (0.000 - 0.002)	0.005 (0.003 - 0.007)	0.001 (0.000 - 0.002)	0.002 (0.001 - 0.003)
NO_3+NO_2 (mg/L)	0.156 (0.041 - 0.898)	0.043 (0.021 - 0.064)	0.133 (0.064 - 0.219)	0.845 (0.479 - 1.175)	0.058 (0.045 - 0.091)	0.125 (0.053 - 0.243)
NH_4 (mg/L)	0.015 (0.007 - 0.036)	0.010 (0.003 - 0.014)	0.007 (0.004 - 0.011)	0.022 (0.014 - 0.035)	0.030 (0.013 - 0.066)	0.019 (0.010 - 0.042)
TP (mg/L)	0.088 (0.069 - 0.148)	0.014 (0.010 - 0.021)	0.063 (0.046 - 0.079)	0.056 (0.042 - 0.076)	0.026 (0.016 - 0.040)	0.037 (0.026 - 0.056)
TN (mg/L)	0.696 (0.464 - 2.960)	0.127 (0.087 - 0.181)	0.344 (0.248 - 0.651)	1.470 (0.810 - 2.030)	0.195 (0.141 - 0.288)	0.341 (0.191 - 0.469)
TIN (mg/L)	0.174 (0.067 - 0.962)	0.054 (0.031 - 0.078)	0.143 (0.076 - 0.229)	0.878 (0.510 - 1.205)	0.102 (0.061 - 0.173)	0.169 (0.078 - 0.280)
FC CFU/100 mL	39.0 (10.0 - 116.0)	6.00 (2.00 - 17.50)	20.0 (4.00 - 42.0)	44.0 (14.0 - 120.0)	56.0 (23.0 - 212.0)	41.5 (14.0 - 121.5)

[1] Highlighted cells indicate locations with greatest median concentration.

Table 14. Median, 25th, and 75th Percentiles (in parentheses) of the Concentration of Each Nutrient and FC Concentration in Irrigation Ditches Collected Concurrently from 2005 to 2008. [1]

Parameter	CW27	Flume RM 7.5	CCD14 and CCD15	CCD1-CCD5	CCD16	GSS	Bluff Ditches
	n = 5	n = 5	n = 23	n = 32	n = 14	n = 30	n = 49
PO_4 (mg/L)	0.005 (0.004-0.019)	0.004 (0.003-0.016)	0.004 (0.002-0.007)	0.031 (0.009-0.112)	0.019 (0.007-0.027)	0.080 (0.046-0.178)	0.087 (0.027-0.161)
NO_3 (mg/L)	0.002 (0.002-0.020)	0.005 (0.003-0.026)	0.004 (0.002-0.036)	0.002 (0.002-0.058)	0.004 (0.002-0.010)	0.035 (0.004-0.176)	0.230 (0.008-1.795)
NO_2 (mg/L)	0.001 (0.000-0.003)	0.000 (0.000-0.002)	0.002 (0.001-0.002)	0.001 (0.001-0.006)	0.001 (0.001-0.002)	0.003 (0.002-0.010)	0.006 (0.002-0.016)
NO_3+NO_2 (mg/L)	0.004 (0.003-0.022)	0.005 (0.004-0.029)	0.008 (0.004-0.038)	0.004 (0.003-0.061)	0.007 (0.004-0.011)	0.049 (0.007-0.189)	0.258 (0.011-1.880)
NH_4 (mg/L)	0.010 (0.004-0.029)	0.013 (0.002-0.028)	0.008 (0.002-0.017)	0.018 (0.006-0.042)	0.034 (0.011-0.050)	0.145 (0.087-0.436)	0.026 (0.013-0.100)
TP (mg/L)	0.017 (0.013-0.043)	0.011 (0.008-0.045)	0.017 (0.014-0.023)	0.031 (0.013-0.085)	0.038 (0.026-0.072)	0.143 (0.082-0.219)	0.170 (0.052-0.391)
TN (mg/L)	0.114 (0.062-0.159)	0.103 (0.073-0.129)	0.140 (0.111-0.260)	0.268 (0.101-1.150)	0.337 (0.224-0.532)	1.390 (0.746-2.350)	2.400 (0.450-5.340)
TIN	0.014 (0.007-0.051)	0.016 (0.007-0.057)	0.038 (0.013-0.051)	0.035 (0.010-0.111)	0.040 (0.014-0.058)	0.304 (0.115-0.711)	0.336 (0.036-2.015)
FC CFU/100 mL	128 (49.0-289)	10.0 (2.00-12.0)	80.0 (26.0-362)	23.5 (4.00-102)	101 (7.00-267)	27.0 (15.5-71.0)	36.0 (6.00-366)

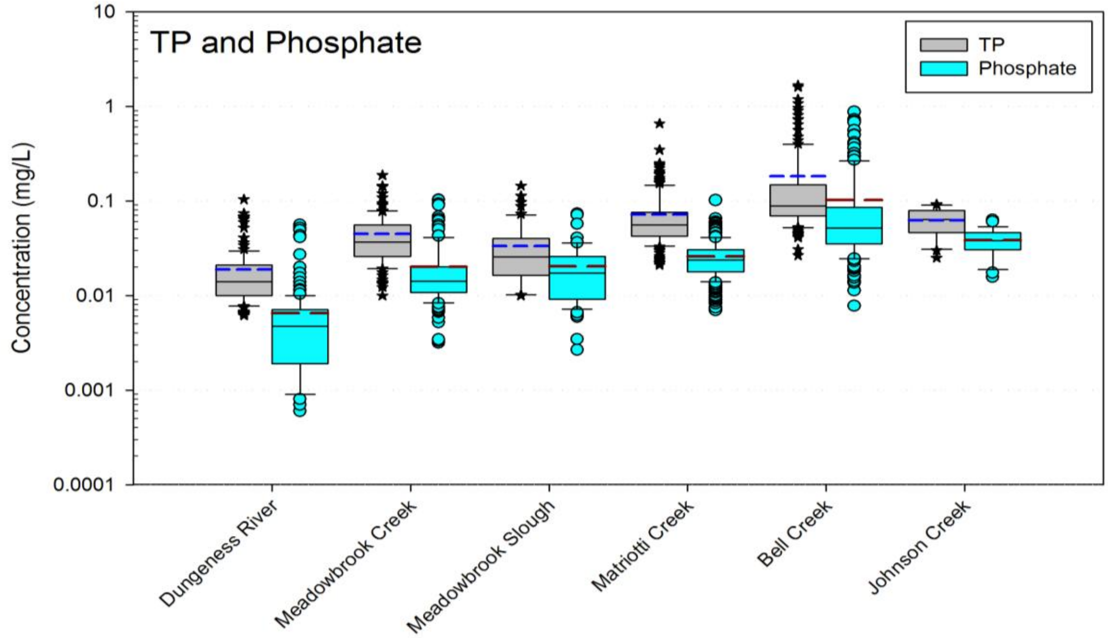
[1] Highlighted cells indicate locations with greatest median concentration.

Table 15. Median, 25th, and 75th Percentiles (in parentheses) of the Concentration of Each Nutrient and FC Concentration Collected from Dungeness Bay DOH Stations between 2006 and 2007. [1]

Nutrient	Station 108	Station 113
	n = 13	n = 14
PO_4 (mg/L)	0.053 (0.050 - 0.068)	0.052 (0.037 – 0.064)
NO_3 (mg/L)	0.232 (0.137 - 0.318)	0.231 (0.112 -0.338)
NO_2 (mg/L)	0.005 (0.004 -0.006)	0.005 (0.003 – 0.0061)
NH_4 (mg/L)	0.049 (0.035 – 0.014)	0.040 (0.019 – 0.058)
TP (mg/L)	0.079 (0.070 – 0.092)	0.068 (0.061 – 0.086)
TN (mg/L)	0.671 (0.479 – 0.891)	0.478 (0.320 – 0.763)
FC CFU/100 mL	2.00 (1.70 - 12.0)	0.001.85 (1.70 - 8.60)

[1] Highlighted cells indicate locations with greatest median concentration.

Figure 25 provides a visual summary of the TP with phosphate and TN with TIN concentrations in the Dungeness River and tributaries. These box and whisker plots show the dominance of the inorganic species for each of these total nutrient concentrations. In addition, both Mattrioti and Bell Creek had the highest median and greatest range in concentrations. Figures 26 and 27 show box plots for the irrigation stations and bluff ditch stations respectively. Although the overall pattern is similar, there are fewer data points for the irrigation ditches, thus reducing the ability to make overall comparisons. The two Dungeness Bay stations also show a similar pattern with respect to the dominance of the inorganic species (Figure 28).



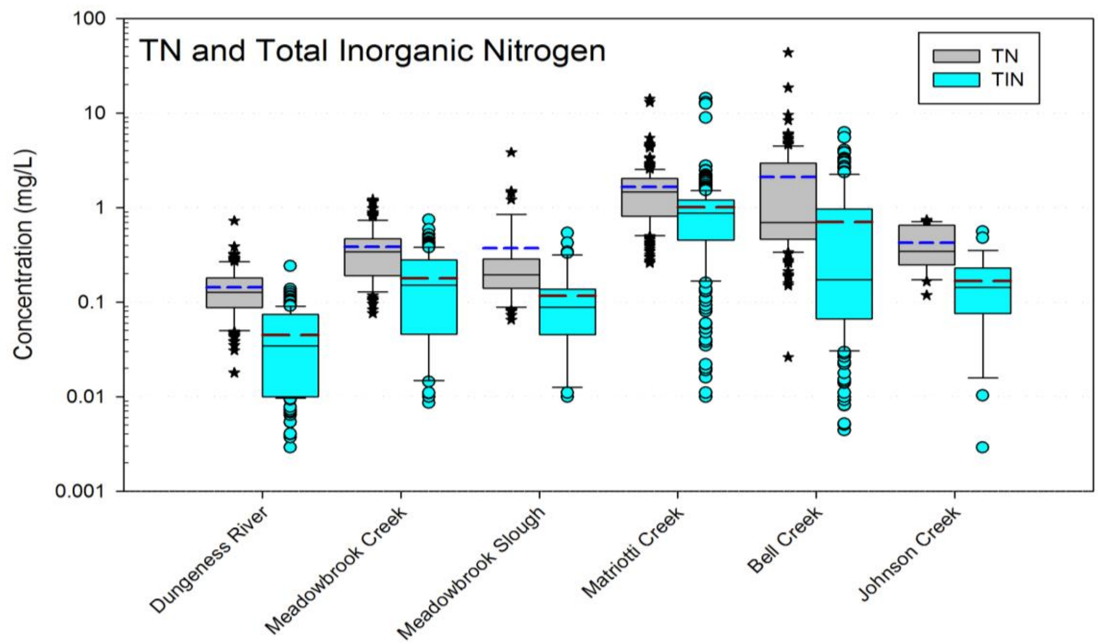


Figure 25. Box and Whisker Plots of Total Phosphorus (TP) Plus Phosphate (top) and Total Nitrogen (TN) Plus Total Inorganic Nitrogen (TIN; bottom) Concentration for Freshwater Water Bodies, Grouped by Tributary and Creek

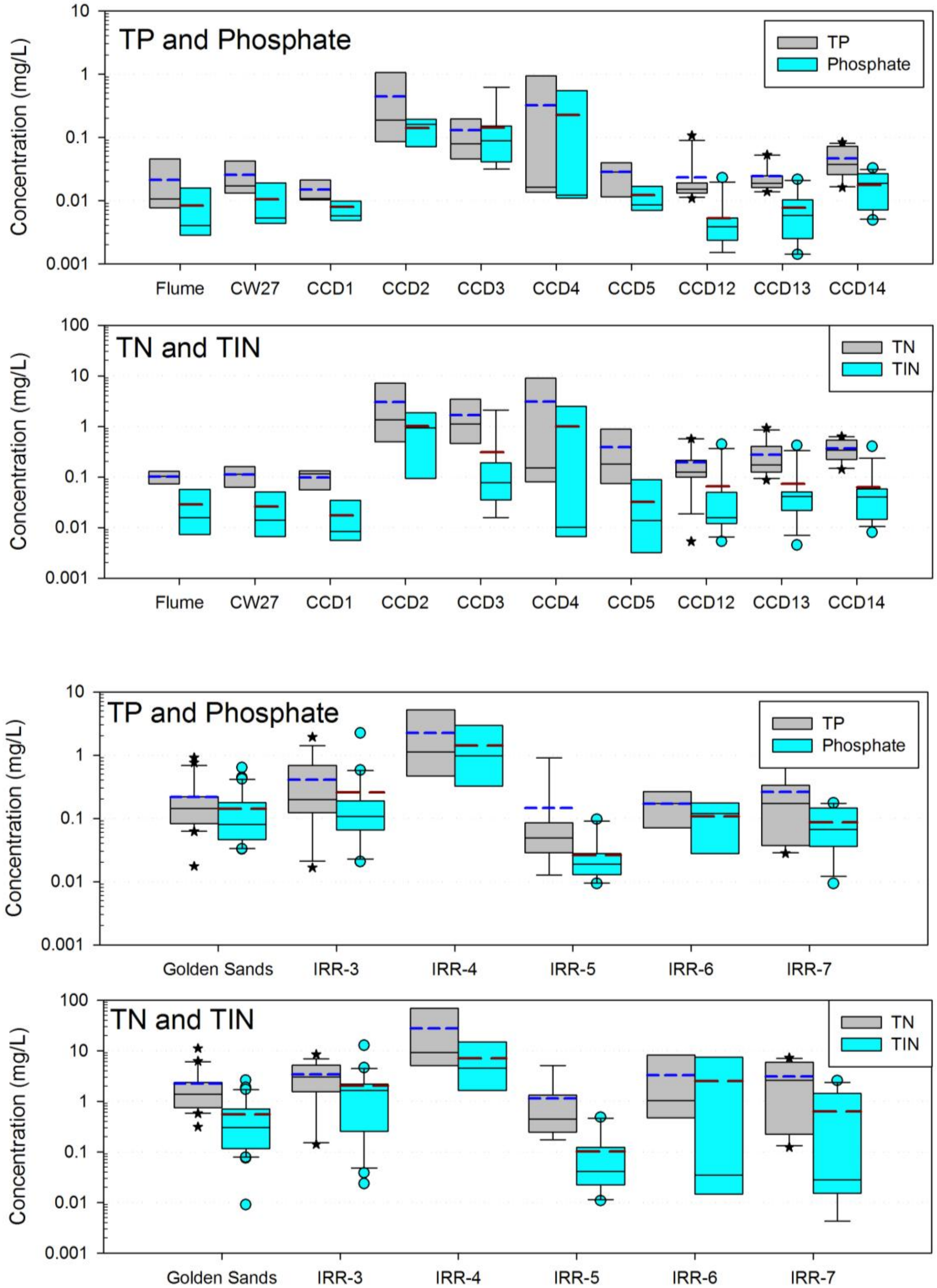


Figure 26. Box and Whisker Plot of Total Phosphorus (TP) Plus Phosphate and Total Nitrogen (TN) Plus Total Inorganic Nitrogen (TIN) Concentration for Freshwater Sampling Stations, Grouped by Type or Location of Discharge.

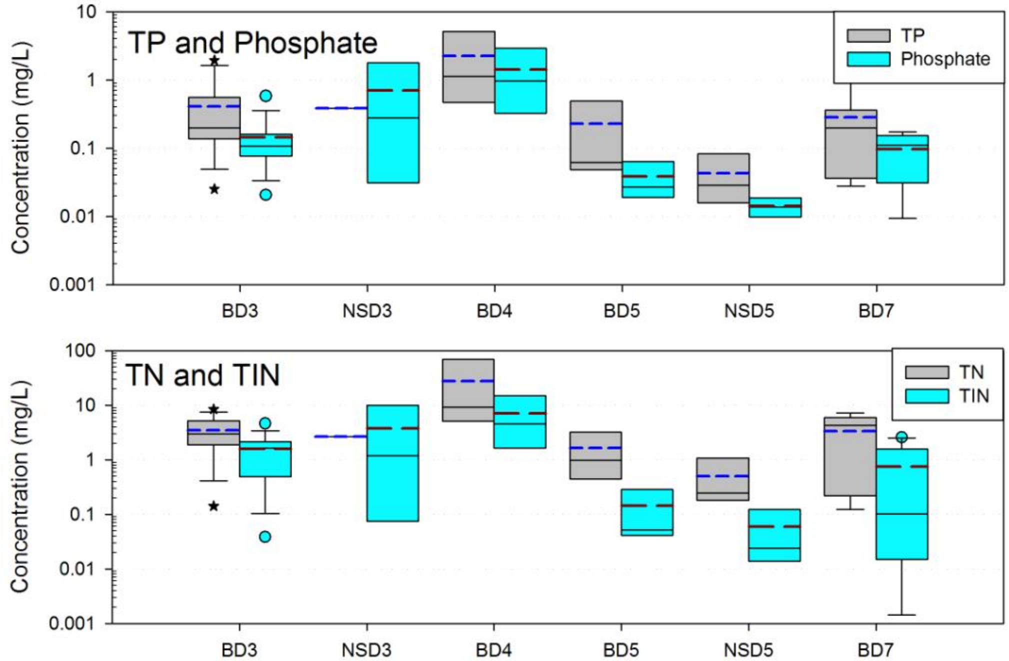


Figure 27. Box and Whisker Plot of Total Phosphorus (TP) Plus Phosphate (top) and Total Nitrogen (TN) Plus Total Inorganic Nitrogen (TIN; bottom) Concentration for Bluff Ditch Sampling Stations.

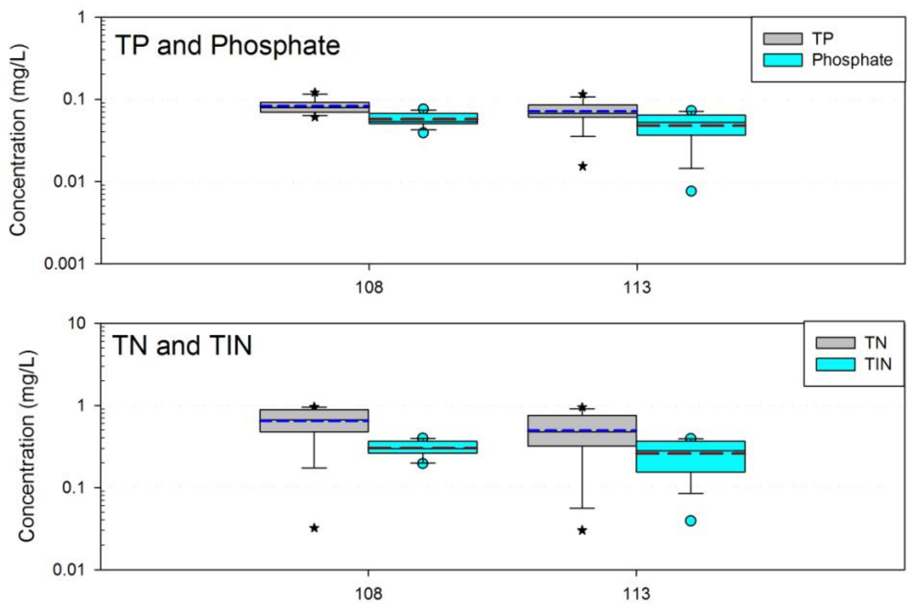


Figure 28. Box and Whisker Plot of Total Phosphorus (TP) Plus Phosphate (top) and Total Nitrogen (TN) Plus Total Inorganic Nitrogen (TIN; bottom) Concentration for Marine DOH Sampling Stations.

Histograms of individual station data are provided for NO_3 and NH_4 (Figure 29), TN and TIN (Figure 30), and PO_4 and TP (Figure 31). Although very little historic nutrient data exists in the Dungeness watershed, some monthly and semi-annual collections of NO_3 and PO_4 occurred between 1959 and 1970 and was collected at Dungeness River Mile 6.4, located near the Hiway 101 bridge crossing. The NO_3 mean concentration for that time period was 0.159 mg/L (n =32). As a visual reference, the mean is shown on Figure 29. This reference value is lower than most other station data, however it is higher than some stations including all Dungeness River stations. It should be noted that very little information was provided on methodology or detection limits, so a comparison with current datasets should take that into account. In Figure 29(a) several bluff stations show higher concentrations of nitrate (BD3, BD4, BD6) as well as several Bell Creek stations (Bel 0.16, 0.8), and all Matriotti Creek stations show slightly elevated nitrate levels. Only BD4 shows elevated ammonia levels, which could be an indication of relatively close proximity to the source. Figure 29(b) plots the same data as Figure 29(a), however the data is represented on a log scale in µg/L, which provides greater detail for stations with lower concentrations. While these concentrations are not elevated, some insight can be gained by examining the nitrate levels relative to ammonia, with higher ammonia levels a possible indicator of source proximity. Figure 30 shows the total nitrogen and total inorganic nitrogen by station. Elevated concentrations of both are present in most of the same stations shown in Figure 29. TP and PO_4 show some similar patterns with respect to stations with elevated values, however levels at Matriotti Creek are much lower (Figure 31). A historic reference value for PO4 is shown in Figure 31. The mean concentration between 1959 and 1970 was 0.016 mg/L (n = 24). Again the levels of phosphorus in the Dungeness River are generally lower than the reference, however the varying methodologies and detection limits need to be taken into account.

The SOC's were evaluated for nutrients in a similar manner as they were for FC (Section 5.2.2, Figure 22, Table 7). For most SOC's there was not enough nutrient data to allow an evaluation of the repair effectiveness. However SOC #2, #4, and #5 had enough observations both pre- and/or post-repair to conduct a statistical analysis. SOC #2 near Golden Sands Slough, did not show a significant reduction in nutrients (NO2, NH4, TP) downstream of the repair at TWG station GSS after the repair was made on 11/05/2006 (ANOVA; $n = 30$; $p > 0.47$). SOC #4 was located farther upstream on Matriotti Creek between MAT3.4 and MAT3.7. This station did show a statistically significant reduction after the repair in NO_2 ($n = 30$; $p < 0.001$) and a nearly significant reduction in NH_4 ($n = 30$; $p = 0.063$). There were only two observations of TP before the repair, therefore this nutrient was not analyzed. SOC #5 located between MAT0.7 and MAT2.0, did not show a significant reduction after the repair in NO2 or NH4 ($n = 30$; $p > 0.26$), however the upstream and downstream stations were some distance apart (1.3 miles). There were only two observations of TP before the repair was made so this nutrient was not analyzed.

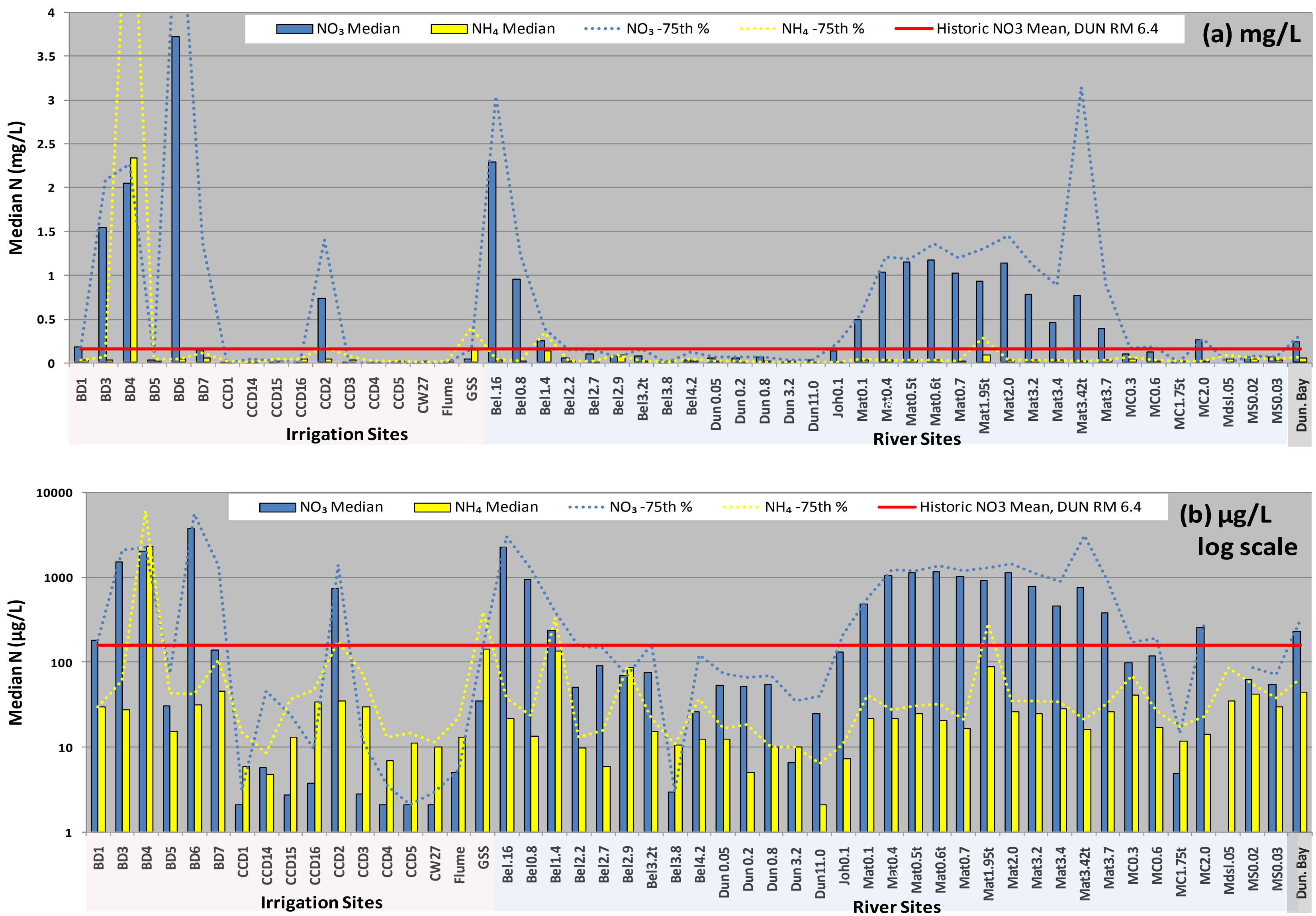


Figure 29. Histogram of the median, and 75[th] percentile of NO_3 and NH_4 for all dates at all study sites, presented as a) mg/L and b) µg/L in log scale highlighting the sites with lower concentrations. Red line indicates 1959 – 1970 mean NO3 taken at Dungeness River Mile 6.4.

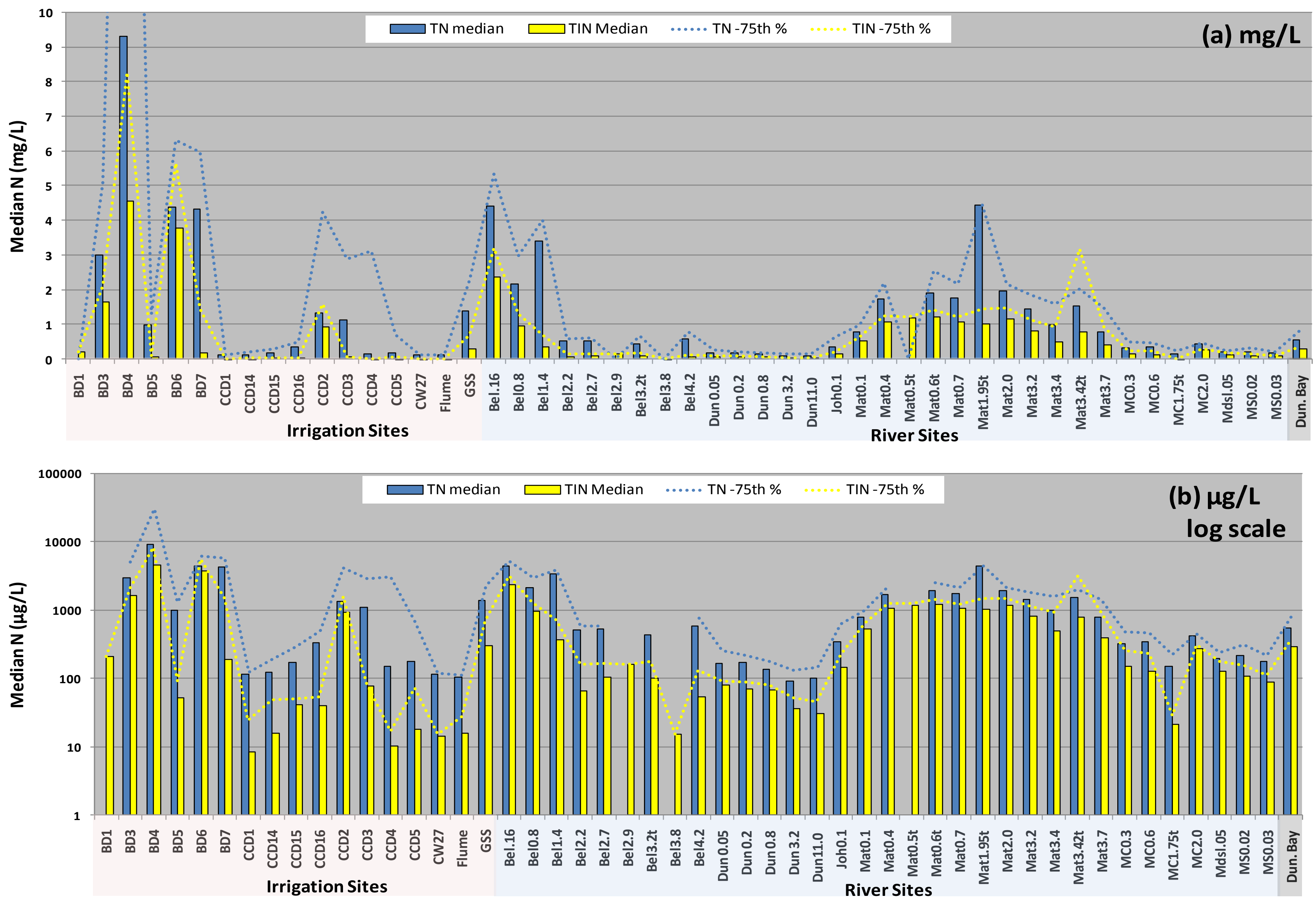


Figure 30. Histogram of the median, and 75th percentile of TN and TIN for all dates at all study sites, presented as a) mg/L, and b) µg/L in log scale highlighting the sites with lower concentrations.

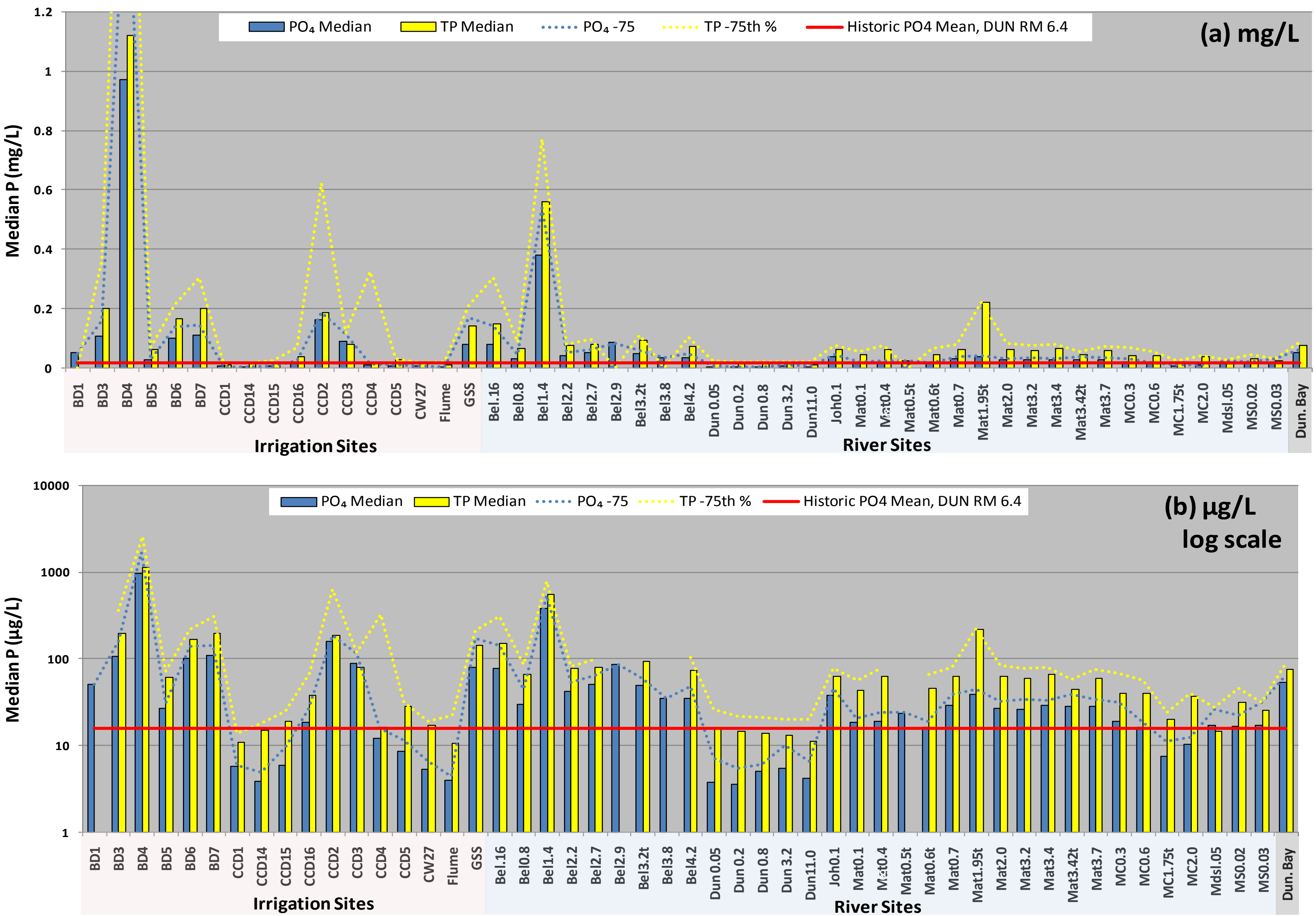


Figure 31. Histogram of the median, and 75th percentile of PO_4 and TP for all dates at all study sites, presented as a) mg/L and b) µg/L in log scale highlighting the sites with lower concentrations. Red line indicates 1959 – 1970 mean PO_4 taken at Dungeness River Mile 6.4

6.3 General Trends in Nutrients

During the TWG study, a majority of the nutrient data was collected in 2006 and 2007 (Table 8, 9 and 10), thus this data was used for the statistical trend analysis. The number of observations within each season, wet (Oct-March) and dry (April-Sept.), for each year was not balanced between rivers or within years. Therefore, similar to the FC trend analysis, a generalized linear model was used to increase the balance in the sample sizes and to test the influence of four key attributes: 1) tributary or ditch, 2) reach location categorized as mouth, lower, middle or upper reach, 3) year, and 4) season (i.e. wet or dry).

Figure 32 shows the trend analysis model results for the ammonia and TIN concentrations. These two nutrients were selected to represent a range in geochemical stability. As discussed above, ammonia is not stable in oxygenated freshwater; therefore, the presence of ammonia concentrations may indicate a localized contribution of sub-surface waters with low or no dissolved oxygen in the tributary near the sampling locations. However nitrate, the dominant form of TIN, is highly soluble and much more stable in oxygenated environments, thus representing the other end of the range in geochemical stability. When examined together, these two nitrogen species can provide information regarding potential sources of nitrogen. There is an apparent difference noted between the median ammonia concentration for the Dungeness River and the much higher concentrations at Meadowbrook Creek, Meadowbrook Slough, Matriotti Creek, and Bell Creek (Figure 32). This would suggest these tributaries are influenced by a local source of ammonia, possibly septic system runoff. Any ammonia entering the Dungeness River, if available, has completely oxidized to nitrate.

Although there are some ammonia differences noted between reach locations (Figure 32), most notably higher levels of ammonia at the mouth reach, tidally influenced freshwater stations should be regarded separately, as marine waters generally have higher background concentrations of nutrients than freshwater. Nutrient concentrations at the mouth of Dungeness Bay (Station Dun. Bay in Figures 28 through 31) were slightly higher than freshwater stations near the mouth of Dungeness River (Dun0.05 and Dun0.2 in Figures 28 through 31).

Minimal seasonal influence was observed with the median ammonia concentrations. Ammonia is a common component in septic system effluent, which generally does not vary seasonally. The lack of a seasonal ammonia distribution is common throughout all regions of the continental United States (Mueller et al. 2006). In the Pacific Northwest, sites with a distinct seasonal pattern are more likely to have seasonally-driven nonpoint sources, such as runoff during the wet season. The TIN data suggests the wet season may be higher than the dry season, but there is insufficient data to support conclusions about long term seasonal shifts.

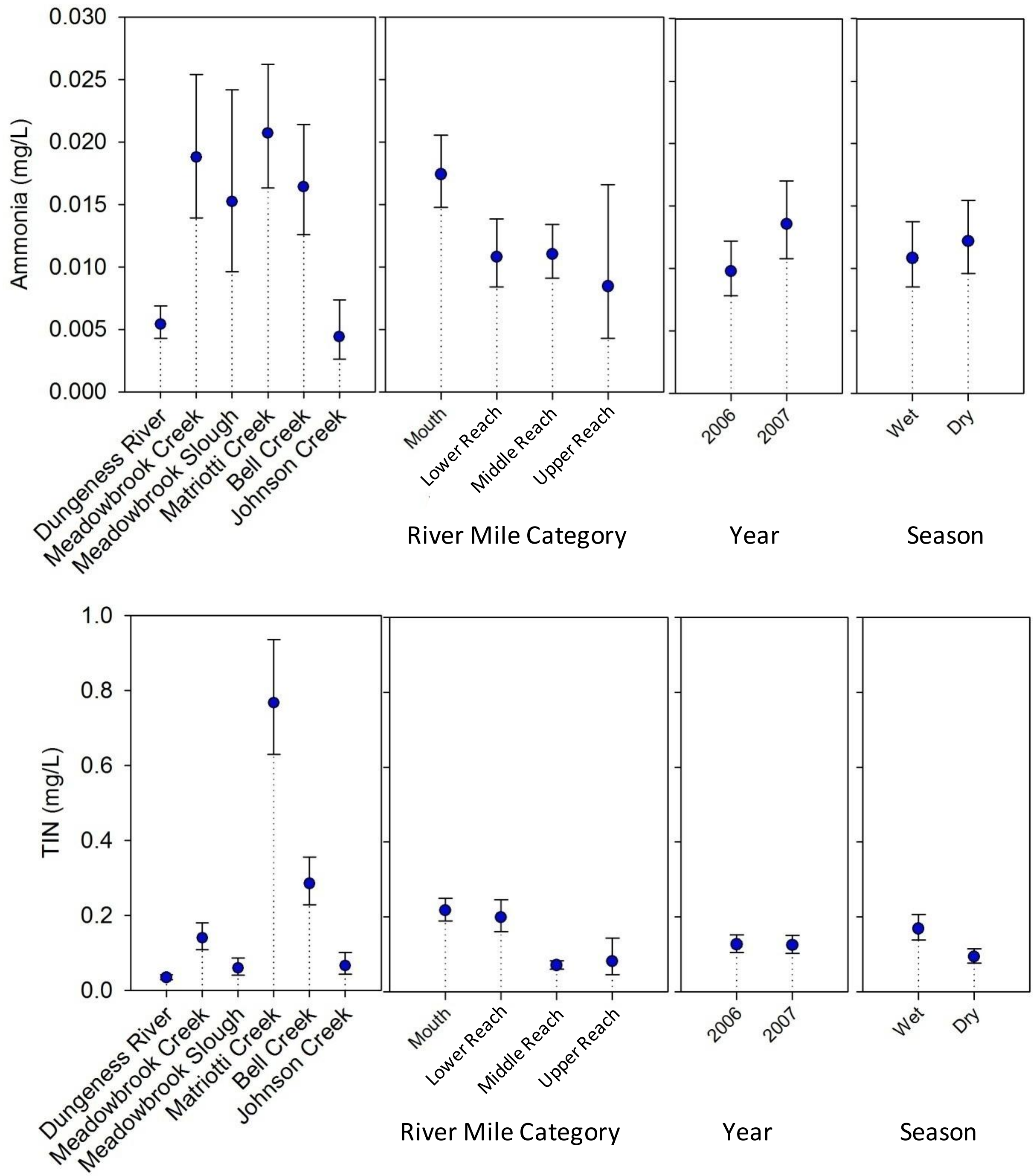


Figure 32. The Geometric Mean and 95% Confidence Interval of Ammonia (top) and Total Inorganic Nitrogen (TIN; bottom) Concentrations by Tributary/Creek (left), River Mile Location (center), Year (right of center), and Season (far right).

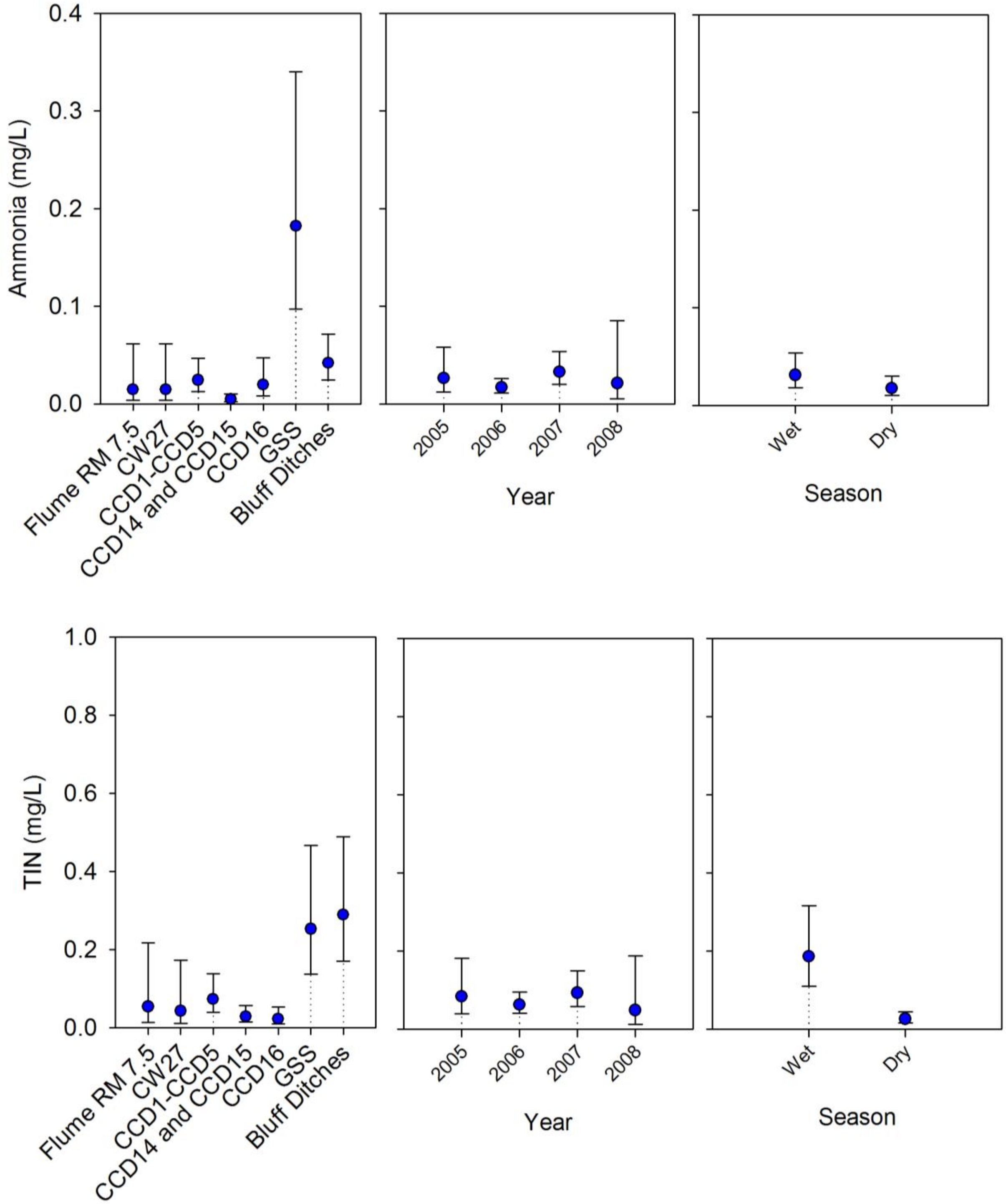


Figure 33. The Geometric Mean and 95% Confidence Interval of Ammonia (top) and Total Inorganic Nitrogen (TIN; bottom) Concentrations by Irrigation Ditch and Other Freshwater Monitoring Stations (left), Year (center), and Season (right).

The TIN data for the tributaries shows an elevated median and range for both Matriotti and Bell Creek (Figure 32). Coupling the TIN and the ammonia data allows some general conclusions about the types of sources at the various sites. For example, Matriotti and Bell Creeks have both elevated ammonia and TIN compared to the other tributaries. This suggests a mixed source of both septic system effluent (ammonia) and anthropogenically enhanced runoff (nitrate) for these tributaries. Further evidence of runoff as a source of nutrients is shown in Figure 31 where phosphate levels are elevated in Bell creek and slightly elevated in Matriotti creek. Meadowbrook Creek and Meadowbrook Slough only show elevated levels of ammonia (Figure 29 and 31) suggesting that these sources may be close to a groundwater influence with a possible septic system influence.

A similar analysis was conducted with the irrigation and bluff ditch locations using all years of data (Figure 33). The ammonia concentrations are considerably higher in the ditches than the tributaries, when comparing Figure 32 and 33. Again, there is no notable seasonality with the ammonia data, however GSS levels are an order of magnitude higher than the other ditches and also have elevated TIN levels due to the much higher concentrations observed in October of each year. In addition, the TIN data suggests more influence from annual precipitation patterns with a statistically significant difference between the wet and dry season. Likewise, the bluff ditches show elevated TIN levels and elevated phosphorus levels (Figure 31) indicating that sources may include anthropogenically enhanced runoff.

7.0 Conclusions and Recommendations

The effectiveness monitoring study has provided the opportunity to explore in greater detail, surface water bacteria and nutrient data that has been collected for the past decade through a variety of projects (including TWG) in the Dungeness watershed. The study also examined the effectiveness of selected demonstration BMP's at remediating fecal contamination, and more importantly, led to an understanding that modifications to sample design for effectiveness monitoring should be made in the future. The analysis has also raised additional questions for further study. The components of the study included:

- A statistical examination of fecal coliform trends in the Dungeness watershed and Dungeness Bay between 1998 and 2008.

- A characterization of the nutrients in the watershed, conducted as part of the TWG study (2005 through 2008).

- A statistical evaluation of the effectiveness of irrigation piping and septic system repairs as BMP demonstrations for remediating fecal coliform bacteria.

In this study, the analysis of water quality data was conducted at multiple scales; site specific as well as at the landscape scale (i.e. river, tributaries, Bay). At the local scale water quality parameters were monitored prior to and following installation of BMP's (e.g. irrigation piping, septic repairs). When possible, monitoring also occurred upstream and downstream of the BMP sites. Water quality monitoring was conducted at stations that had been selected in earlier years due to suspected water quality problems, and/or stations that had been included as part of a TMDL conducted in 1999-2000 (Sargeant, 2002). While these sites allowed for continuity of a longer term data record via continued monitoring through the TWG program, the locations were not originally established in such a manner that would allow for a statistically robust examination of overall landscape trends in the watershed, nor were the sites necessarily the best locations to evaluate select BMPs. In addition, the spatial and temporal sampling approach was not a statistically balanced design, as sampling depended on a variety of factors including property access, seasonal availability of running water (e.g. irrigation ditches), and budget constraints. In order to minimize the effect of unequal sample sizes through time and space, stations were grouped by location (e.g. a tributary or ditch) and by season, which allowed for a broader look at watershed impacts. However, results are constrained by the lack of a statistically robust sample design, and trends associated by reach (i.e. mouth, lower, middle, upper reach) or by tributary should be interpreted as hypotheses or ideas that warrant further investigation, rather than definitive conclusions.

Freshwater fecal coliform (FC) data from more than 2000 samples collected between 1998 and 2008 was analyzed for trends over time and by geographic area. The samples were collected from over 55 stations along the Dungeness River, its tributaries, nearby creeks and irrigation ditches. The samples collected during this time period had natural high variability with respect to concentration, sometimes differing by several orders of magnitude. In order to examine the possible sources of variability within the data, regression models were used to partition potential sources (tributary, month, season, and year) that could be linked to the variation. Based on these models, there was no significant increase or decrease in the annual mean FC concentration during the time period examined. The year 2000 had the highest geometric mean concentration. There was a distinct seasonal pattern noted, with the dry season (April through September) having significantly higher FC concentration than the wet season (October through March). There was also a decrease in FC concentration with increasing distance from the mouth of the river or any given tributary or creek. The Dungeness River had the lowest median concentration of bacteria of all freshwater bodies examined (i.e. Dungeness River, Matriotti Creek, Meadowbrook Creek, Meadowbrook Slough, Bell Creek, and Johnson creek), ranging between 2 and 12 CFU/100 ml. Of the Dungeness tributaries, Matriotti Creek had the highest median concentration, ranging between 31 and 103 CFU/100 ml. Irrigation ditches were significantly higher than the Dungeness River as well.

The evaluation of effectiveness for mitigating FC in the Dungeness watershed focused primarily on concentration data, rather than data based on in-stream loading (i.e. concentration times flow). Flow information was collected from a number of TWG monitoring stations, however it was not consistently available, and an in-depth analysis of loading was impractical. FC loading is an important concept with respect to inputs transported to the marine environment and shellfish harvest areas. An examination of FC concentration vs. loading was examined at two sites with adequate data; one site was on the Dungeness River at Mile 0.8 with relatively large flow, and one was an irrigation ditch that emptied into the Bay. While the concentration at the irrigation ditch was higher than the Dungeness River, the FC loading was several orders of magnitude greater at the Dungeness River site (Figure 15).

Fecal coliform data from adjacent marine waters was also analyzed between 1998 and 2008. Over 1,200 FC observations from 13 stations within Dungeness Bay were monitored monthly by the Washington State Department of Health as part of the National Shellfish Sanitation Program. Similar to the freshwater data, there was no significant increase or decrease in FC for the time period examined, although 2002 had the highest geometric mean concentration of all years and individual station trends did exist. Again, there was a distinct seasonal trend; however the pattern was the opposite of that observed at the freshwater stations, with significantly higher FC concentrations found during the wet season in marine waters compared to the dry season.

Nutrient samples were collected from selected freshwater stations during routine FC monitoring as part of the TWG study (2005 through 2008). Over 830 nutrient observations were analyzed, including phosphate (PO_4), nitrate (NO_3), nitrite (NO_2), ammonia (NH_4), total nitrogen (TN) and total phosphorus (TP). For a general reference, nutrient data was compared to historic data (nitrate and phosphate) collected at another location in the upper Dungeness River between 1959 and 1970. For the most part, recent nutrient levels in the lower Dungeness watershed were not very different than historic values, although a direct site comparison could not be made. There were, however, several trends in the data that warrant further investigation.

Ammonia concentrations were slightly elevated at all Dungeness tributaries and Bell Creek compared to those detected in the River or Johnson Creek. In addition, ammonia levels were an order of magnitude higher at Golden Sands Slough, another freshwater station close to the Bay. Ammonia is generally found in areas with low oxygen availability (i.e. groundwater) and is rapidly oxidized to nitrate in contact with surface waters. Its presence in surface waters, even at low levels, could indicate close proximity to potential sources such as septic systems or agricultural runoff. There were minimal seasonal changes noted in ammonia concentrations, another possible indication of septic system influence since septic system input generally varies less by season than other anthropogenic nutrient sources incorporated into seasonal runoff. Total inorganic nitrogen (TIN) was higher in Matriotti Creek, Bell Creek, Golden Sands Slough and the irrigation ditches compared to other water bodies and stations. TIN is an indicator of a number of possible anthropogenic inputs. Overall, the TIN data was higher during the wet season compared to the dry season, a possible indication of anthropogenic runoff. PO_4 and TP concentrations showed a similar trend of elevated concentrations in Bell Creek, Golden Sands Slough and the irrigation ditches, with higher concentrations during the wet seasons compared to the dry season.

There was no significant correlation between nutrients (NH_4, NO_3, NO_2, TIN, TN, PO_4, and TP), freshwater FC concentrations, and daily rainfall determined for the days of sample collection. The lack of a statistically significant correlation may be indicative of varying sources of FC and nutrients; however analysis of rainfall patterns over a longer duration might demonstrate a correlation.

Two BMP demonstrations conducted during the TWG study (irrigation piping and septic repairs) were analyzed on a site specific scale to determine their effectiveness at removal of FC bacteria and/or nutrients. A third BMP (mycoremediation) was analyzed for effectiveness in a separate report (Thomas et al. 2009). To the extent possible, water samples were collected upstream and downstream of each BMP activity, as well as before and after implementation of a BMP. Piping irrigation ditches is considered a BMP for water conservation by preventing conveyance losses. Since the water conveyance system is enclosed in a pipe, the possibility of contaminants entering the system is greatly reduced, and if the pipeline is closed at the end, there is no spilling of excess tailwater at the downstream end of the irrigation system.

Monitoring for the effectiveness of irrigation piping was problematic in the sense that downstream samples could not be collected in most cases since the source water was eliminated. Median concentrations from the two upstream stations were 10 and 128 CFU/100 ml. At one downstream location, the tailwater from a bluff ditch station (IRR-3) that emptied into the Bay was monitored after piping was complete because regulations required that a stormwater conveyance ditch be reconstructed above the pipe to continue to convey runoff. After piping, the FC concentration in the stormwater runoff conveyance was not significantly different than before the piping. Further analysis examined the impact of piping on tailwater discharge into Dungeness Bay, comparing data before and after the piping at three marine monitoring sites located near the freshwater bluff ditch sites. One marine station, DOH-110 was significantly different before and after piping. However, the geometric mean at this site before piping was 7 CFU/100 ml and after the piping was 4 CFU/100 ml. While this was statistically significant, it has little meaning from a water quality improvement standpoint.

A number of benefits of irrigation piping can clearly be demonstrated such as water conservation, reduced ditch maintenance and efficient water delivery, however the empirical evidence of reduction in FC was not clearly apparent from this study. In the case where an irrigation ditch was piped to eliminate tailwater, but the piped ditch closely coupled the path of a stormwater runoff conveyance into the Bay, the benefits were reduced. However, the potential source of contamination to this ditch is from a much smaller geographic area than prior to piping when several miles of open irrigation ditch led to this discharge location.

Effectiveness monitoring of a second BMP activity, septic system repairs, was examined as part of the TWG study. Nine direct discharge septic repairs (out of a total of 53 TWG repairs) were completed and analyzed for FC bacteria and nutrient removal. Samples were collected upstream and downstream of each septic repair where possible, as well as before and after the repair. In all cases, the nearest routine monitoring station, either upstream and/or downstream of a repair, was used for analysis. In general, for almost all septic repairs there was no significant difference between upstream and downstream FC levels based on the closest TWG monitoring site. In addition, there was no significant difference before and after a septic repair at those monitoring sites. Nutrients were examined in the same way, however in most cases there was not enough nutrient data to allow an evaluation of the repair effectiveness. Of the three repairs that could be evaluated, one repair showed a significant reduction in nitrite between the upstream and downstream station, before and after the repair. In this case the sample locations were relatively close to the repair, whereas results from other septic repair locations were confounded by a greater distance between the monitoring sites and the location of the repair.

While the benefit of implementing septic system repairs is clear, the monitoring method used to detect repair effectiveness, in hindsight, was not sensitive enough to detect a change at the site specific or local scale. Closest established monitoring stations were used, regardless of the location of the repair, rather than establishing monitoring stations in close proximity to repair locations. Hence, a statistical decrease in FC contamination as a result of septic system repairs was not observed, in part because the monitoring sites were located too far away from the repair to detect a difference. This coupled with the high natural variability in FC concentrations resulted in no statistically significant findings. The nutrient results from one case where a significant decrease was detected indicate that monitoring stations placed in closer proximity to the repair or source in question would have a better chance of detecting a significant difference. This type of monitoring could be used for detecting failing septic systems or evaluating repair effectiveness, if monitoring locations were selected specifically for that purpose.

The overall results of this study have not shown an improvement in surface water quality with respect to fecal coliform bacteria in the Dungeness watershed or Dungeness Bay within the last 10 years. However, water quality conditions have not declined within the watershed either. This is notable when considering the population within the Dungeness watershed has steadily increased during this time period. Population pressures have resulted in greater use of onsite sewage treatment systems and a shift in land use including an increase of impervious surfaces, which has likely imposed additional pressures on the watershed and Bay. The observed “steady state” condition of water quality may be due in some part to BMP measures that have been implemented as a result of urban and rural development in the watershed. Additionally, local education and outreach programs have focused on ways to mitigate for bacterial contamination resulting in an increased awareness and responsiveness within the local community.

Recommendations

The effectiveness monitoring study provided an opportunity for the first time, to explore surface water quality data in the Dungeness watershed from a broader perspective than has generally been possible in the past from smaller, specifically targeted projects. For this study, datasets from past, recent, and ongoing programs in the Dungeness watershed and Dungeness Bay were combined to evaluate overall trends from the past decade. In addition, the success of selected BMP demonstrations was evaluated at a local scale, leading to an understanding of the importance of sample design in evaluating effectiveness. The Effectiveness Monitoring study has provided new insights regarding the status of water quality in the watershed, highlighted questions and identified areas in need of broader evaluation and modifications to the existing water quality monitoring strategies. Implementing these recommendations and evaluating the results, as an integral part of an ongoing adaptive management approach, will better inform concurrent management actions to improve water quality in the Dungeness watershed.

Based on the results from this effectiveness monitoring study, we offer the following recommendations:

- **Evaluate Results in Broader Context -** Evaluate the FC and nutrient results from the effectiveness monitoring study in the broader context of other types of studies that have been conducted in the Dungeness watershed (e.g. TMDL's, Dungeness Bay circulation study, Microbial Source tracking) as well as ongoing studies (e.g. TMDL effectiveness monitoring) in order to develop an improved framework for moving forward with modifications to the existing water quality monitoring strategies (see next three bullets)..

- **Fecal Coliform Water Quality Monitoring Strategy Modifications** - Re-assess and modify the overall fecal coliform water quality monitoring strategy for the Dungeness watershed and develop sample designs for 1) a statistically balanced long–term dataset that will allow evaluation of landscape-scale watershed changes, 2) continued acquisition of evaluative data as site specific questions arise, and 3) storm water runoff collection and analysis. Incorporate data collection of both concentration and loading information as equally important components.

- **Nutrient Water Quality Monitoring Strategy Modifications** - Incorporate nutrient sampling into site specific and long-term sampling designs in the watershed. This is an important water quality parameter that can provide additional insight regarding ground water conveyance and surface water runoff contaminants (e.g. human and animal waste, fertilizers, industrial pollutants).

- **On-Site Septic System Water Quality Monitoring Strategy Modifications** - Continue to refine tools to detect on-site septic system failures and evaluate septic system repairs. Evaluate a modification of the effectiveness monitoring approach that incorporates monitoring stations located in closer proximity (upstream and downstream) of a targeted site, and incorporate both FC and nutrient collection (ammonia and nitrate) into the monitoring design.

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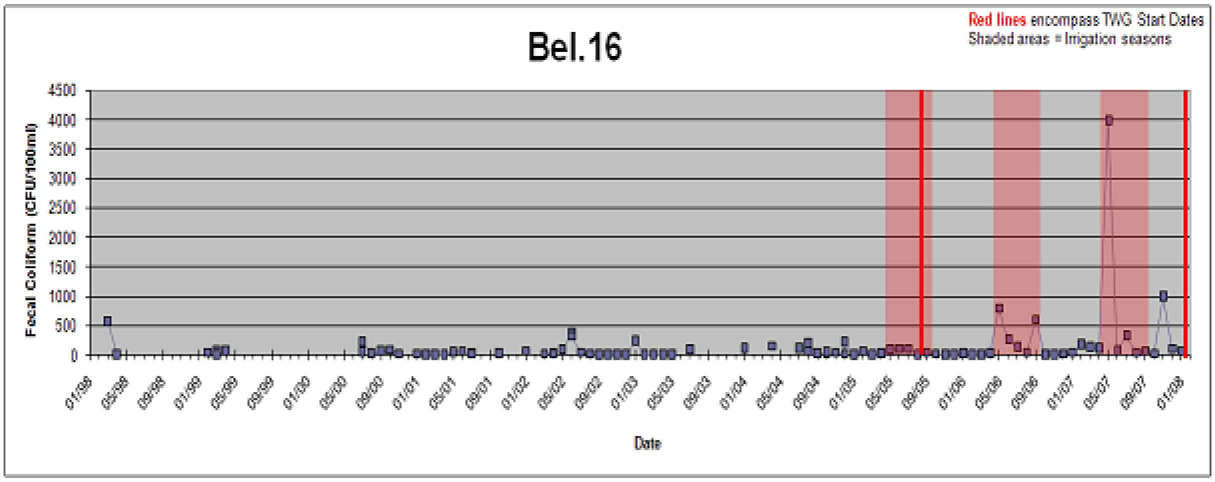
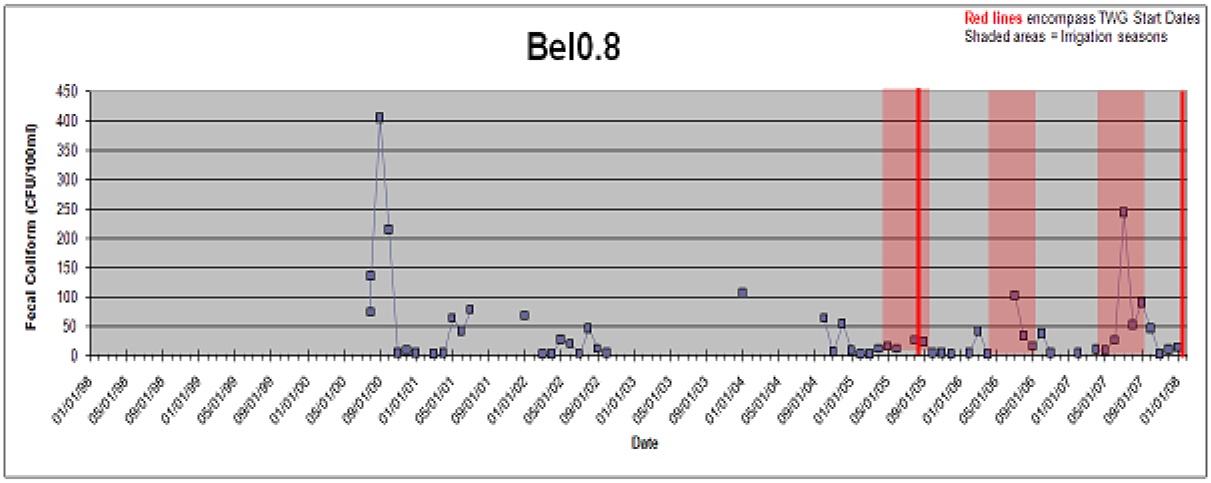
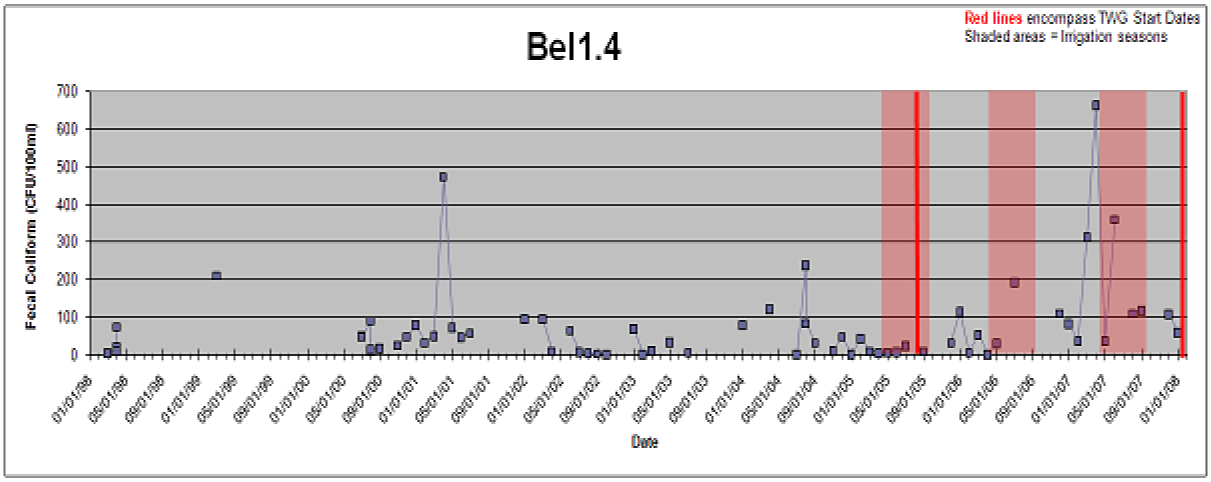
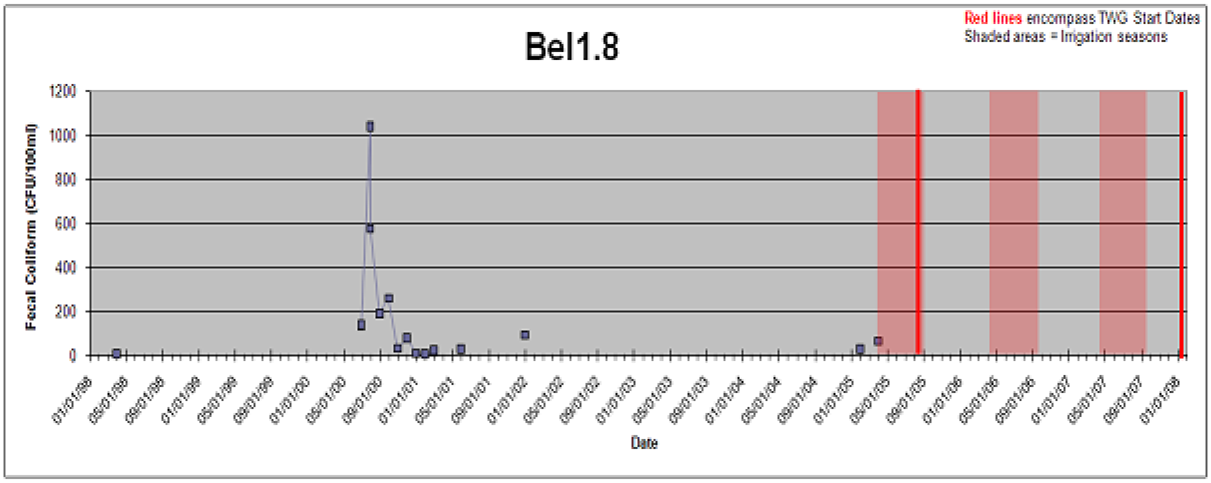
Appendix A

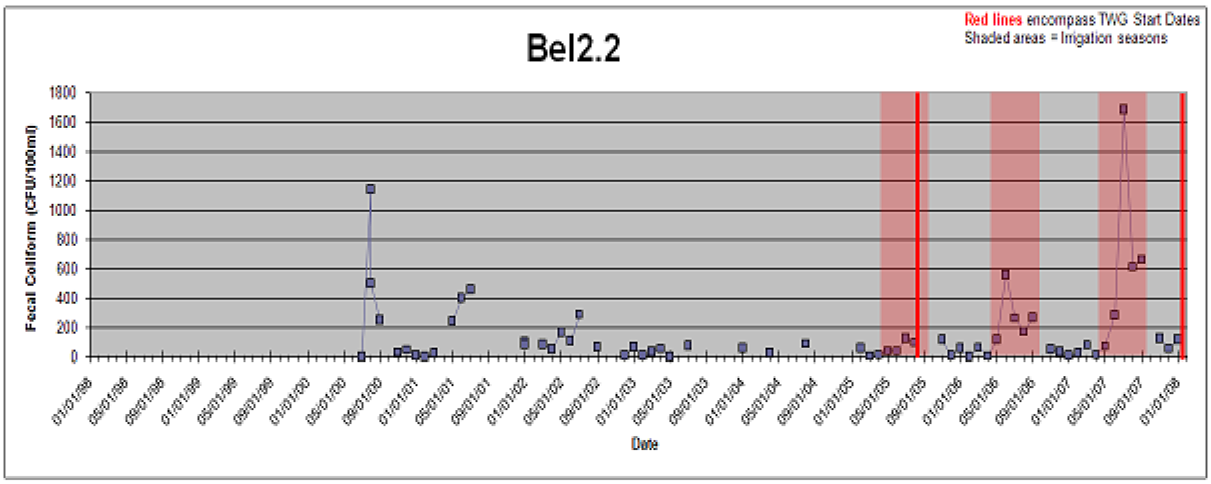
Fecal Coliform Concentrations at TWG monitoring sites

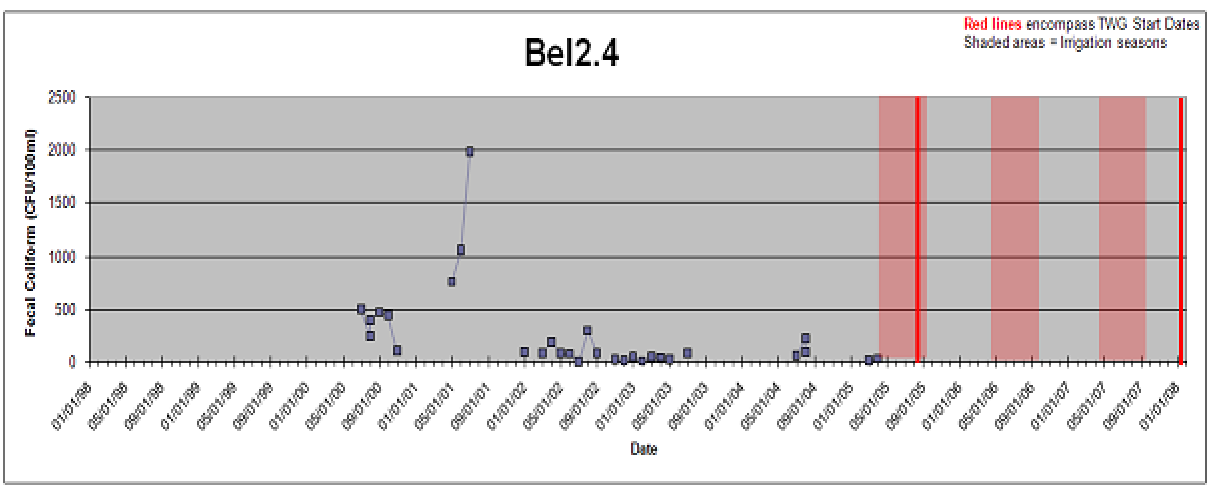

Bel.16
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

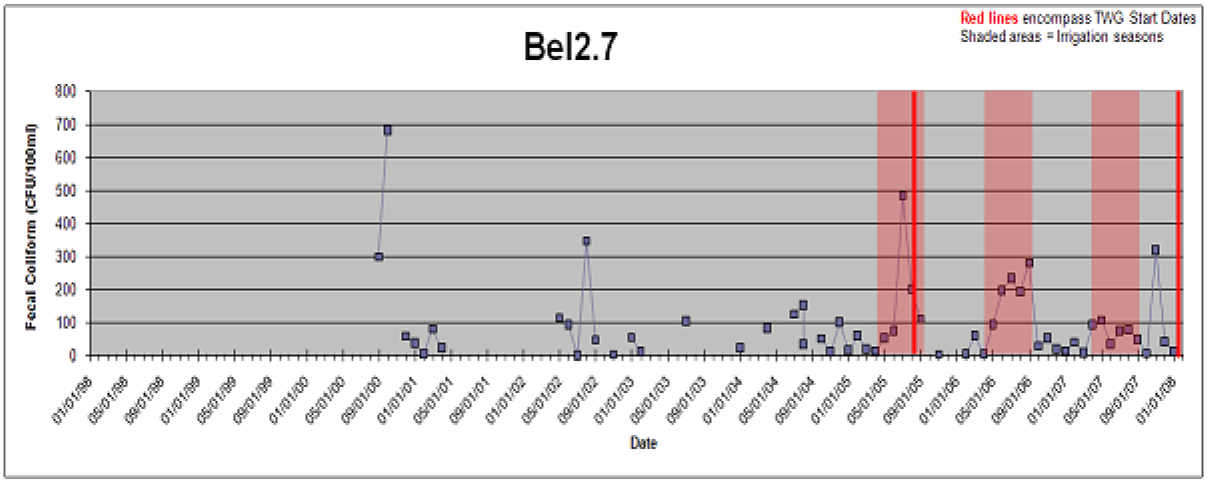

Bel0.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

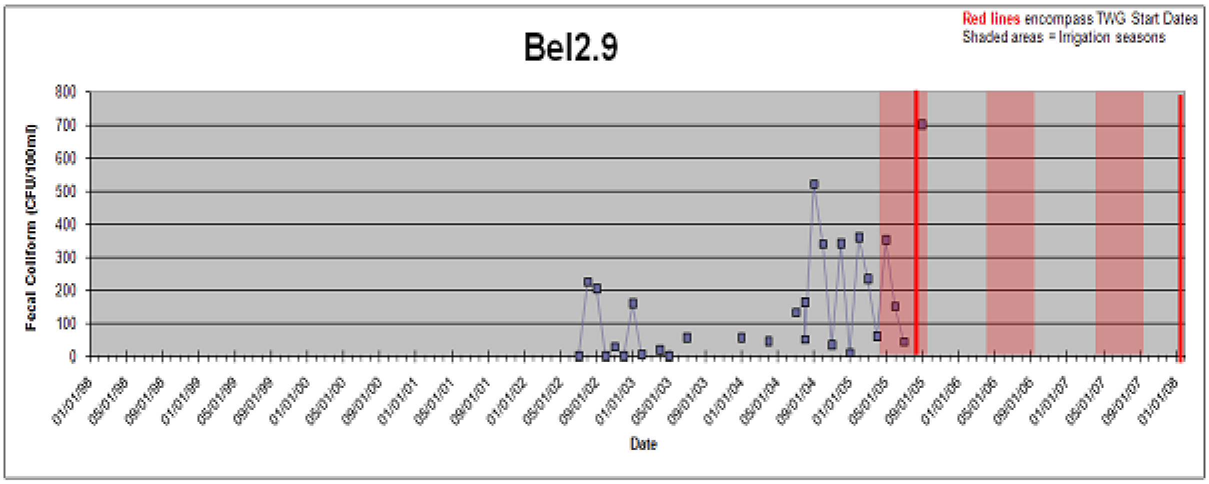

Bel1.4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

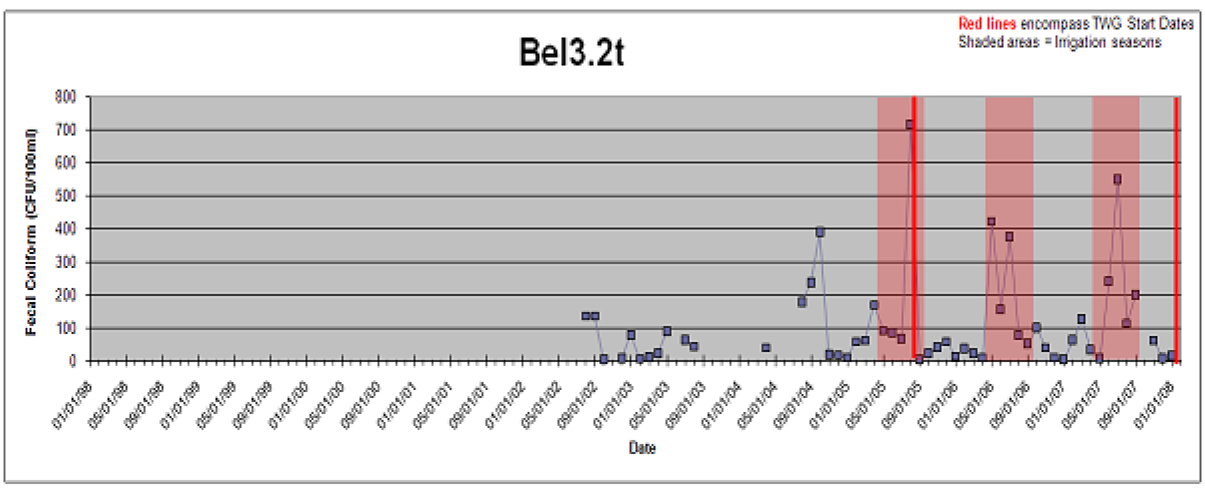

Bel1.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
1200
1000
800
600
400
200
0
Date

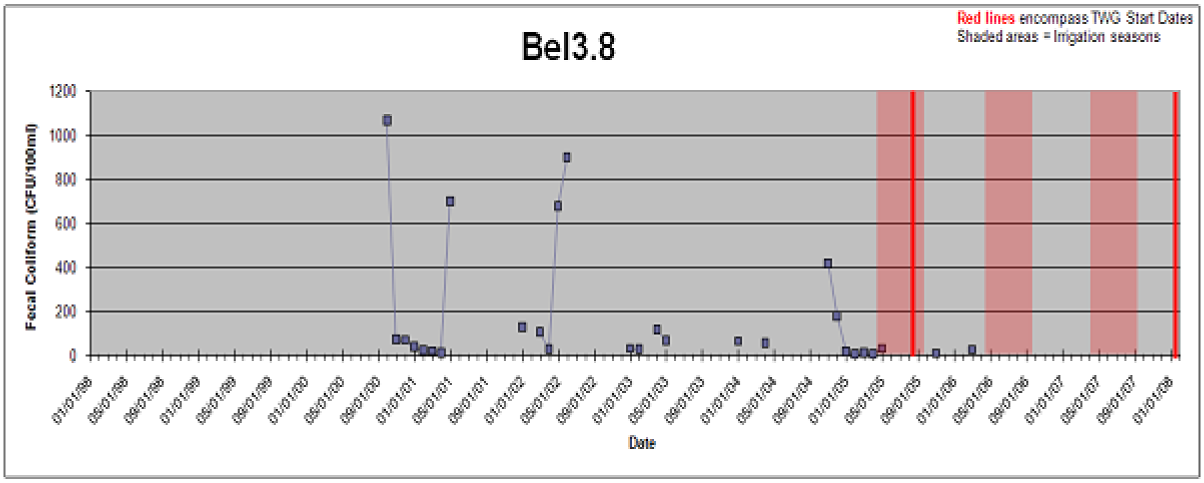

Bel2.2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
1800
1600
1400
1200
1000
800
600
400
200
0
Date

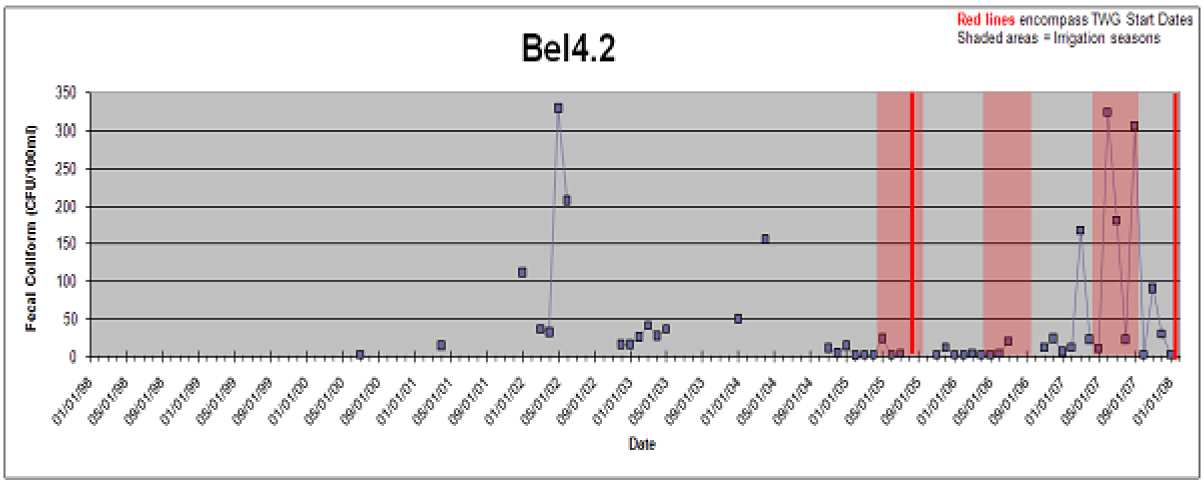

Bel2.4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
2500
2000
1500
1000
500
0
Date

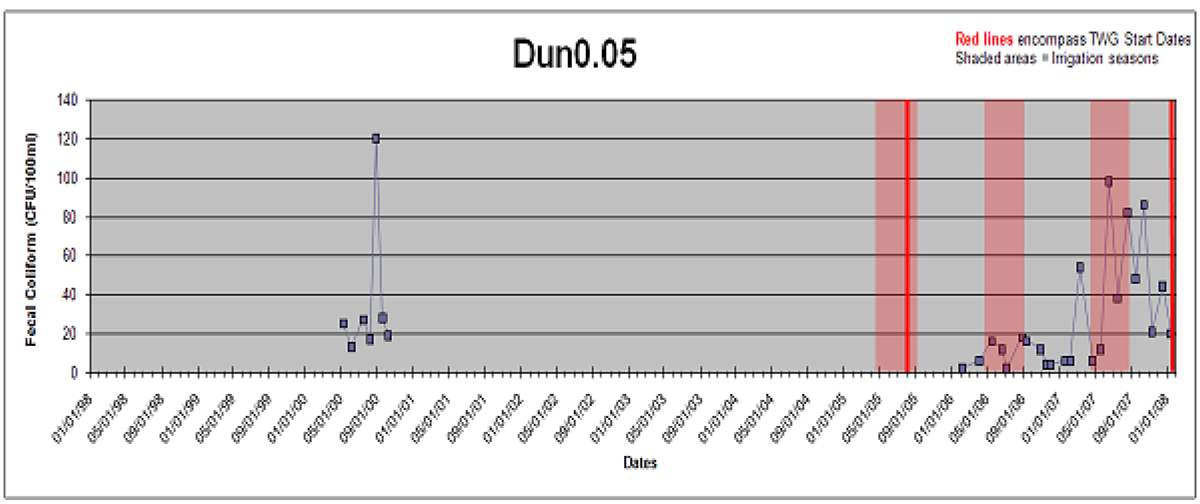

Bel2.7
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0 100 200 300 400 500 600 700 800
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

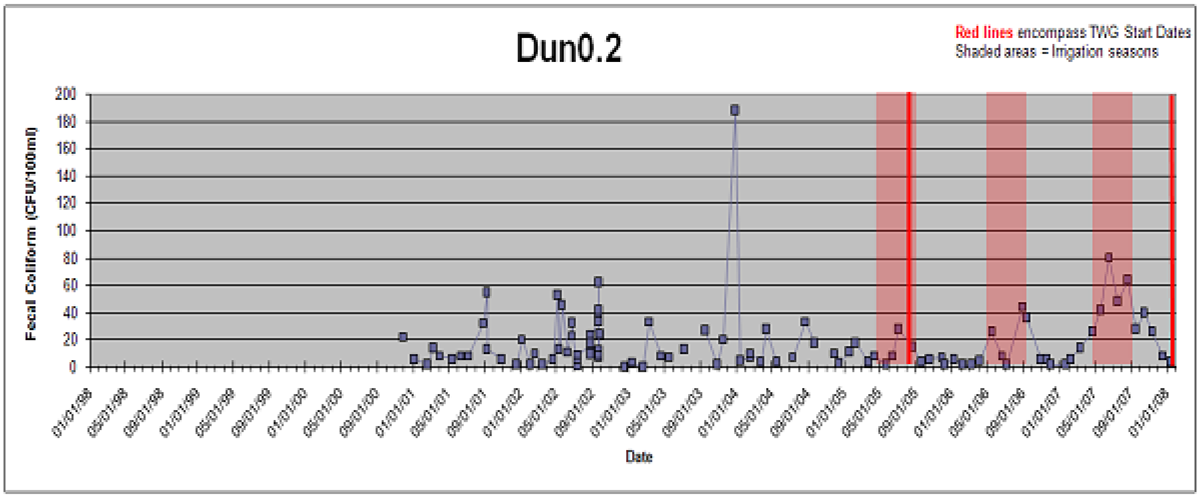

Bel2.9
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0 100 200 300 400 500 600 700 800
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

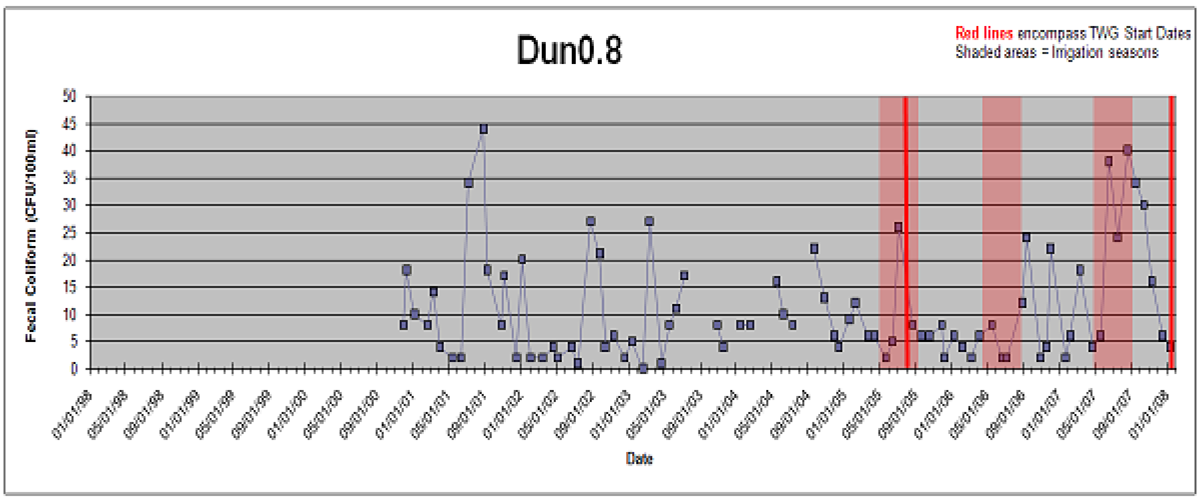

Bel3.2t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0 100 200 300 400 500 600 700 800
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

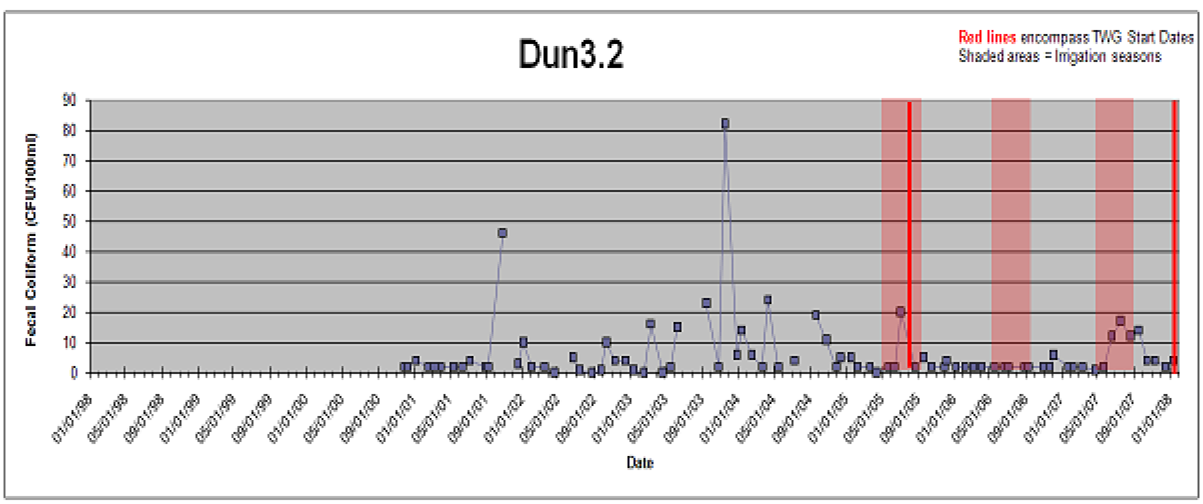

Bel3.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
1200
1000
800
600
400
200
0
Date

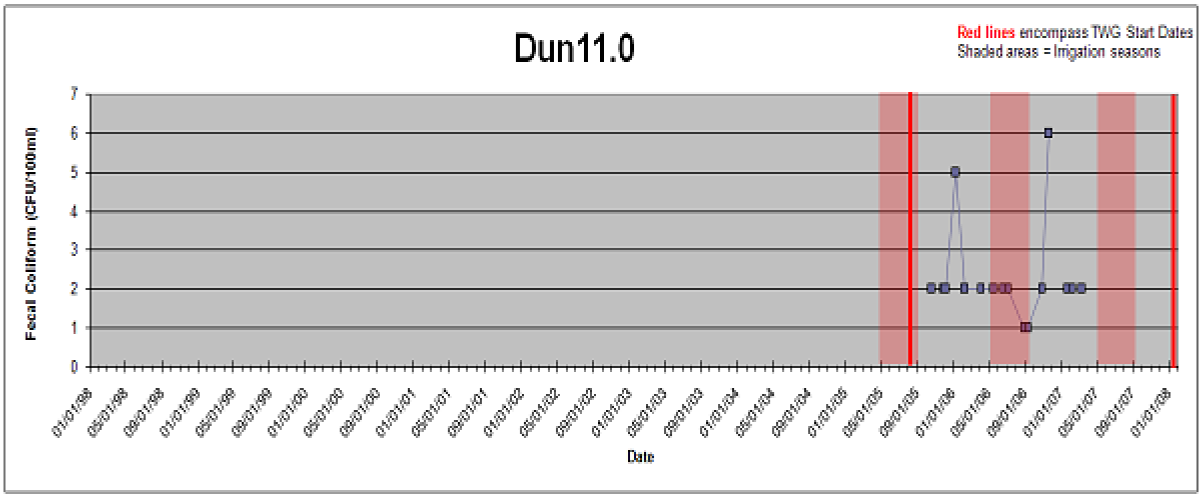

Bel4.2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
350
300
250
200
150
100
50
0
Date


Dun0.05
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
140
120
100
80
60
40
20
0
Dates

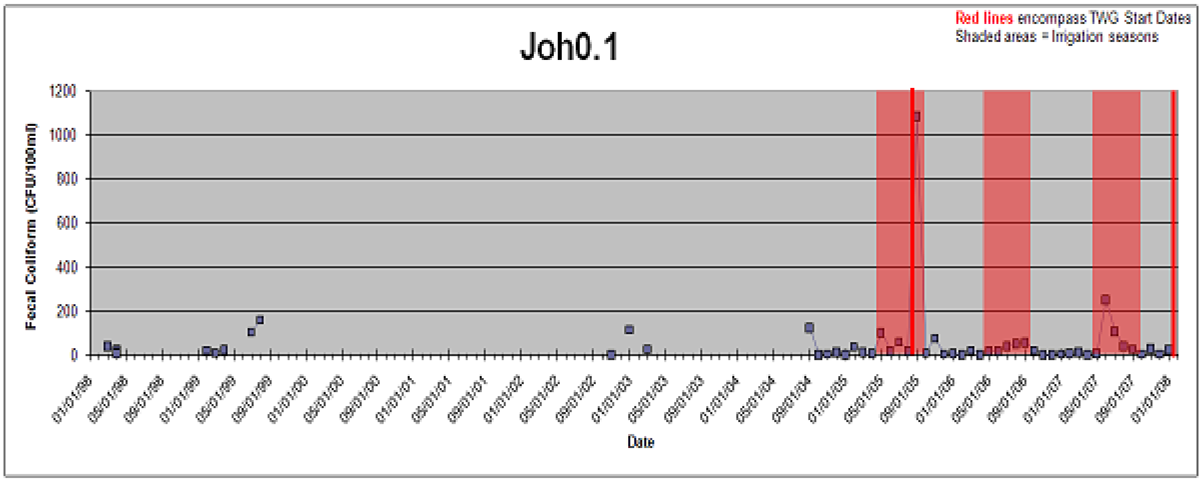

Dun0.2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Dun0.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

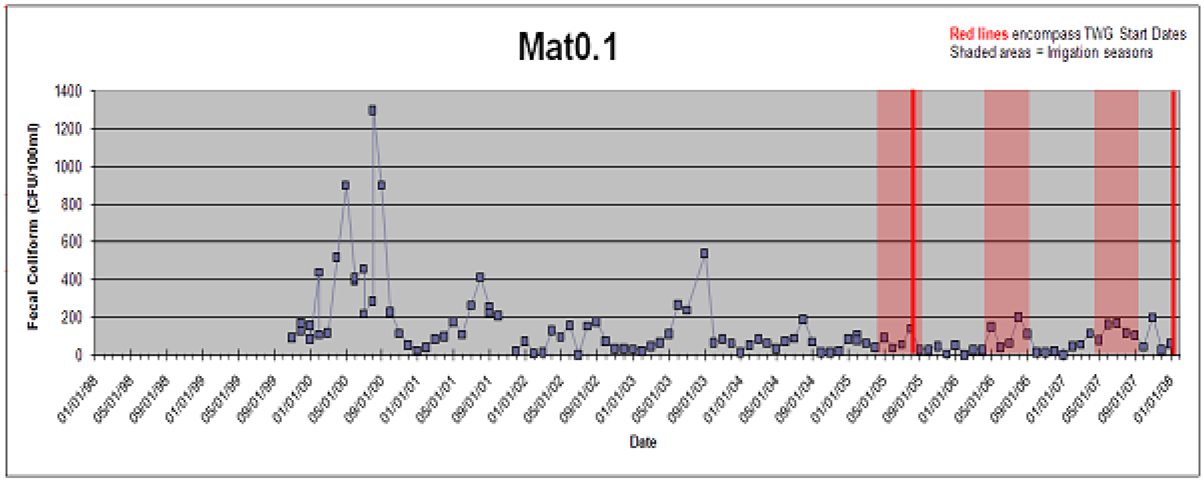

Dun3.2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date



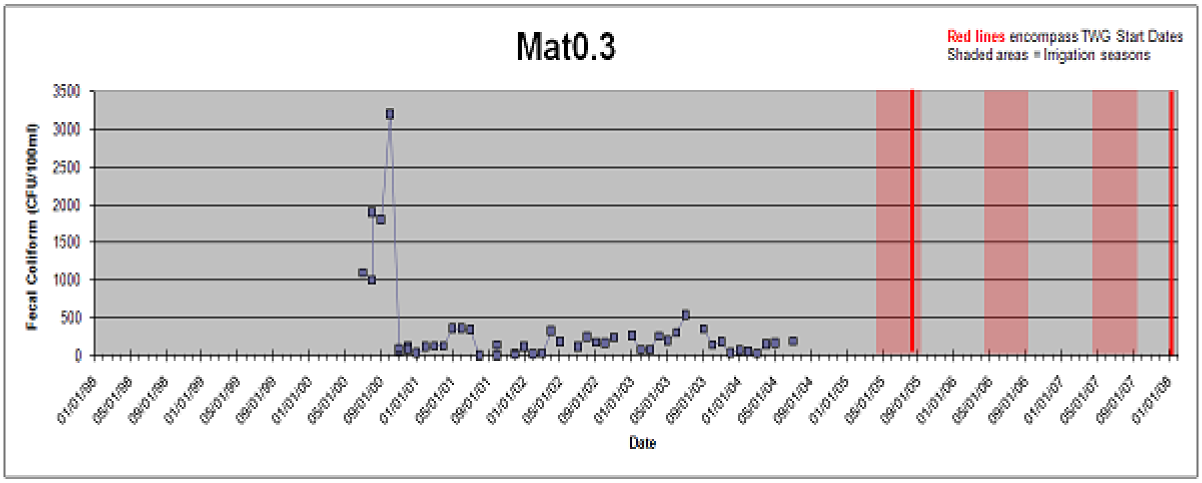
Dun11.0
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date



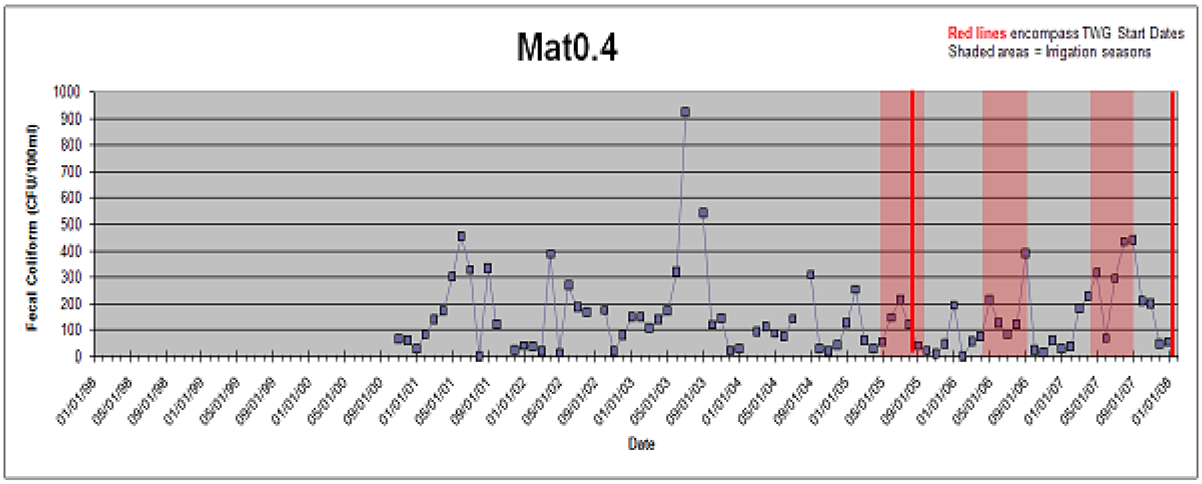
Joh0.1
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date



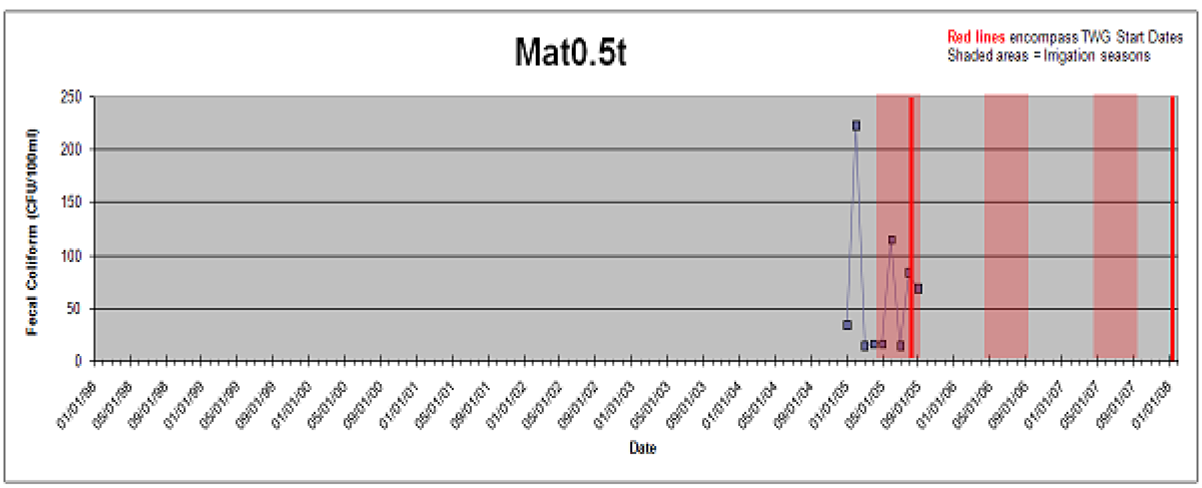
Mat0.1
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date



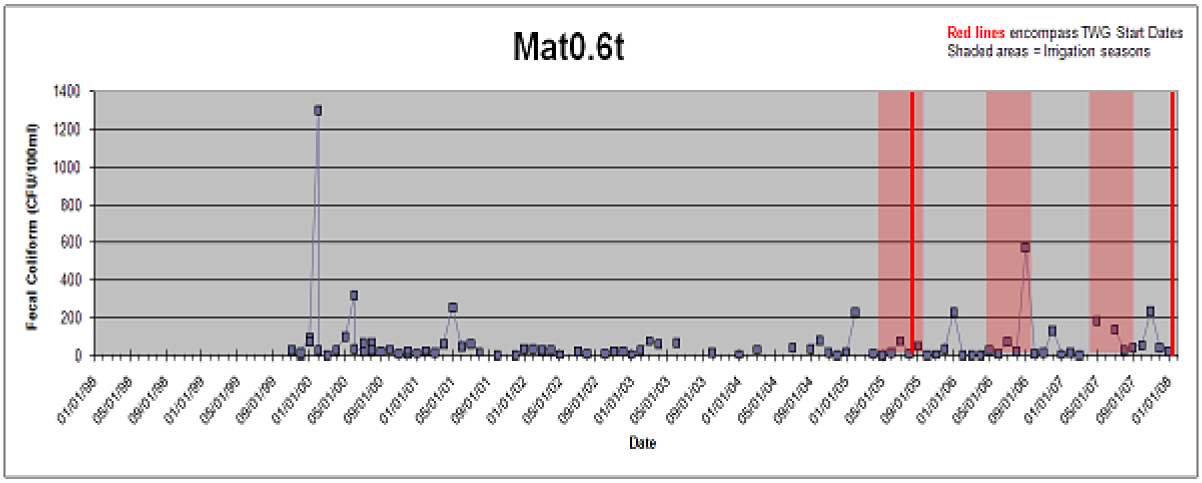
Mat0.3
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

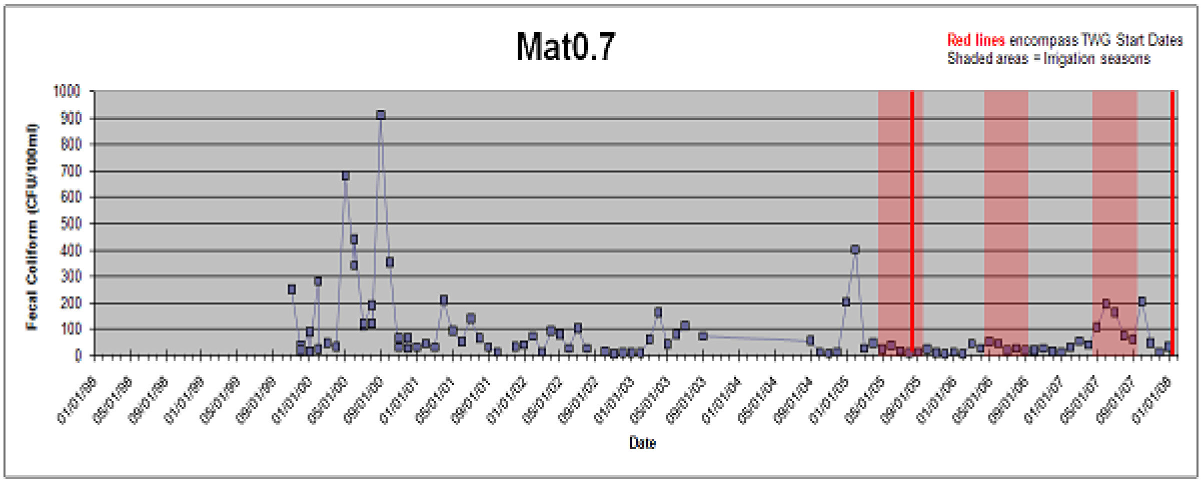


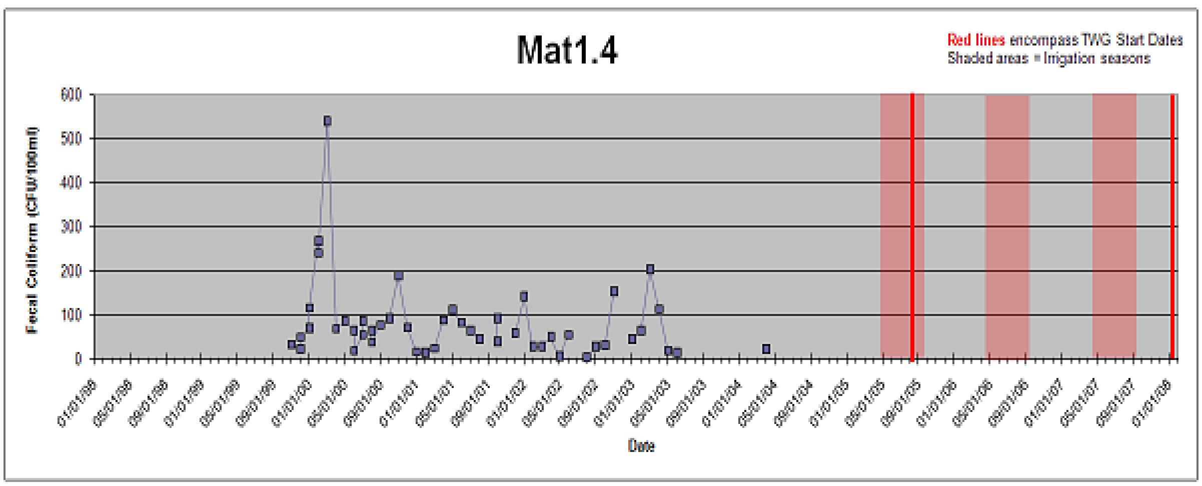
Mat0.4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

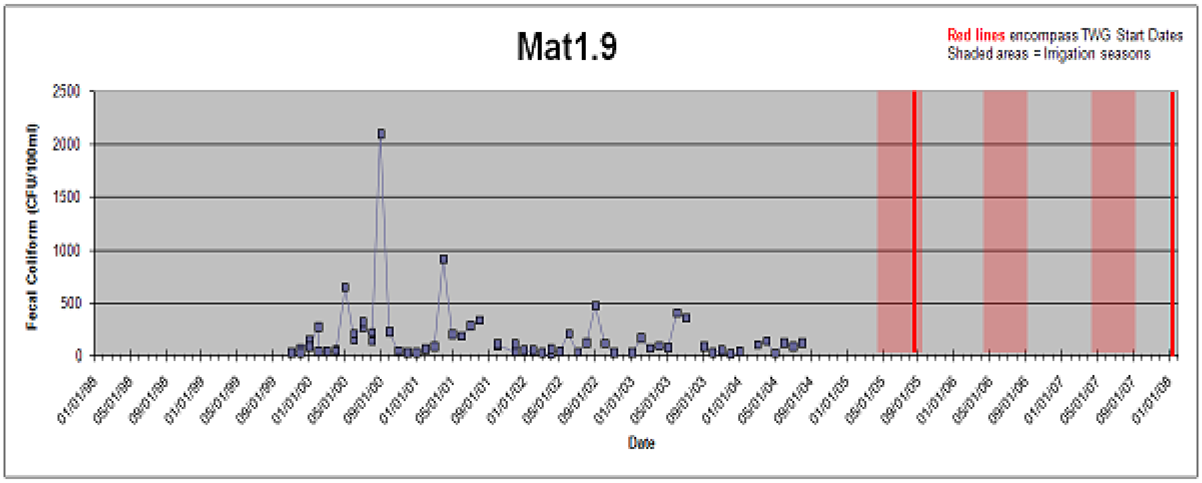


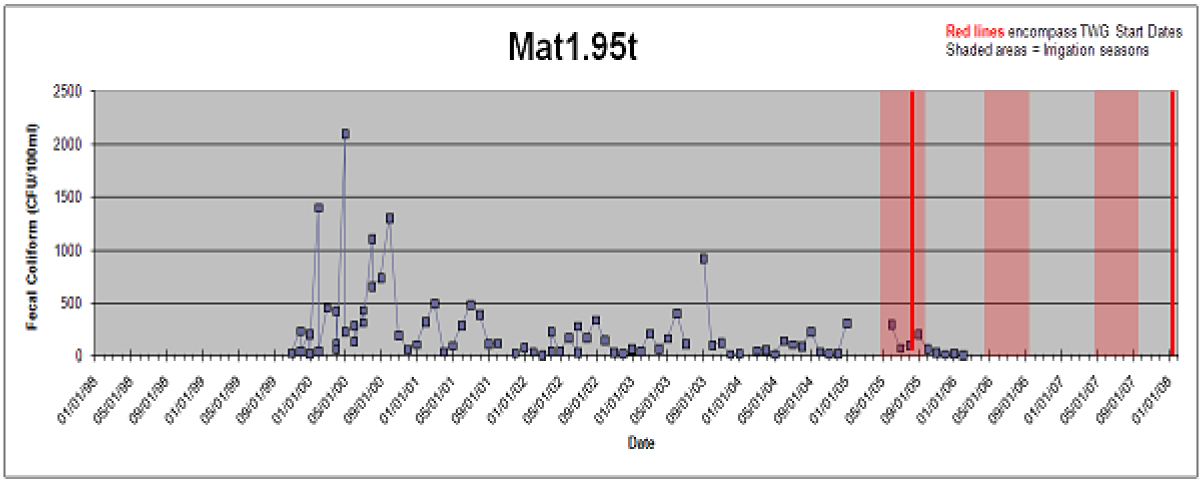
Mat0.5t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

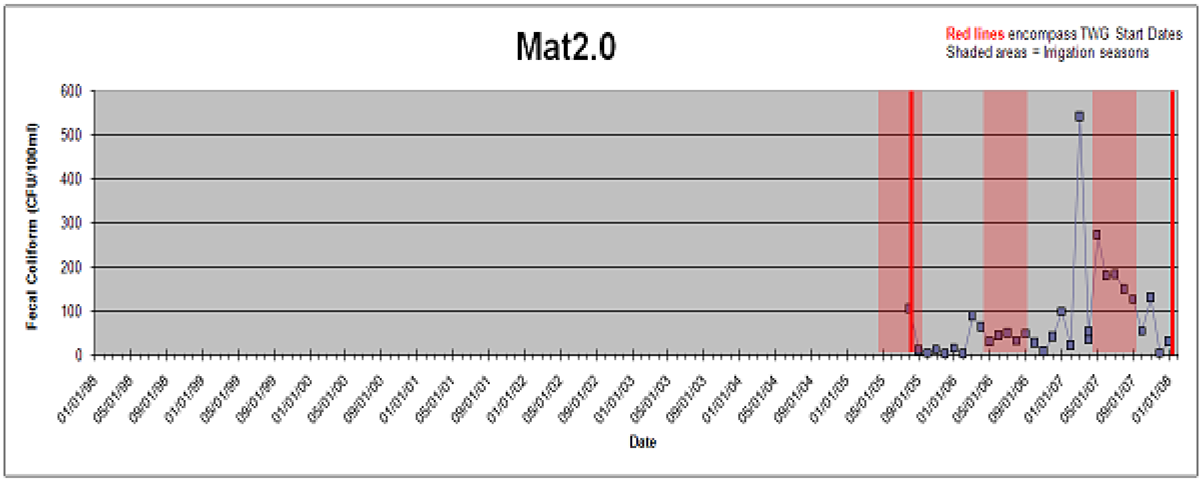

Mat0.6t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

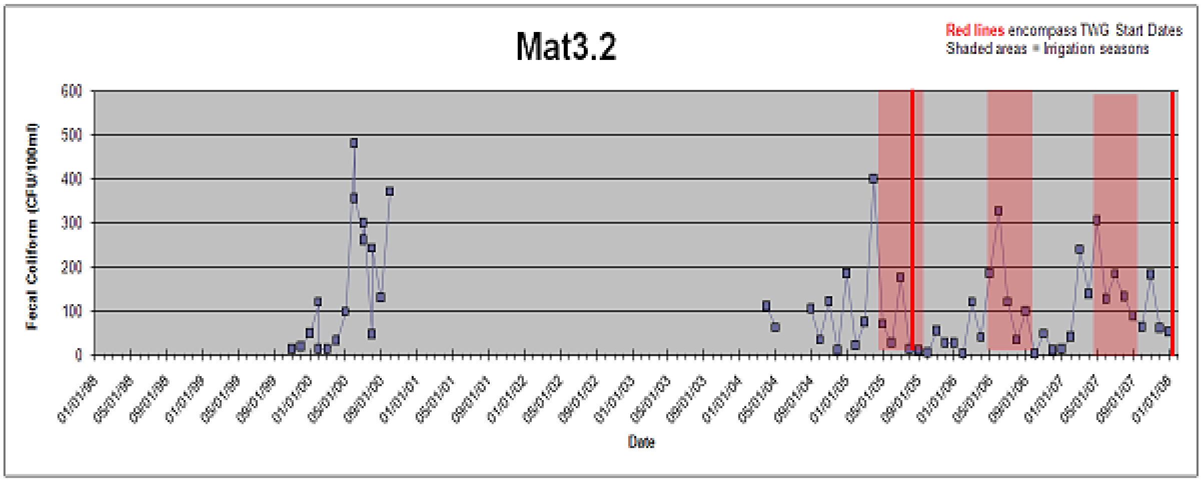

Mat0.7
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Mat1.4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Mat1.9
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Mat1.95t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Mat2.0
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date


Mat3.2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
600
500
400
300
200
100
0
01/01/98
05/01/98
09/01/98
01/01/99
05/01/99
09/01/99
01/01/00
05/01/00
09/01/00
01/01/01
05/01/01
09/01/01
01/01/02
05/01/02
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05/01/03
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05/01/04
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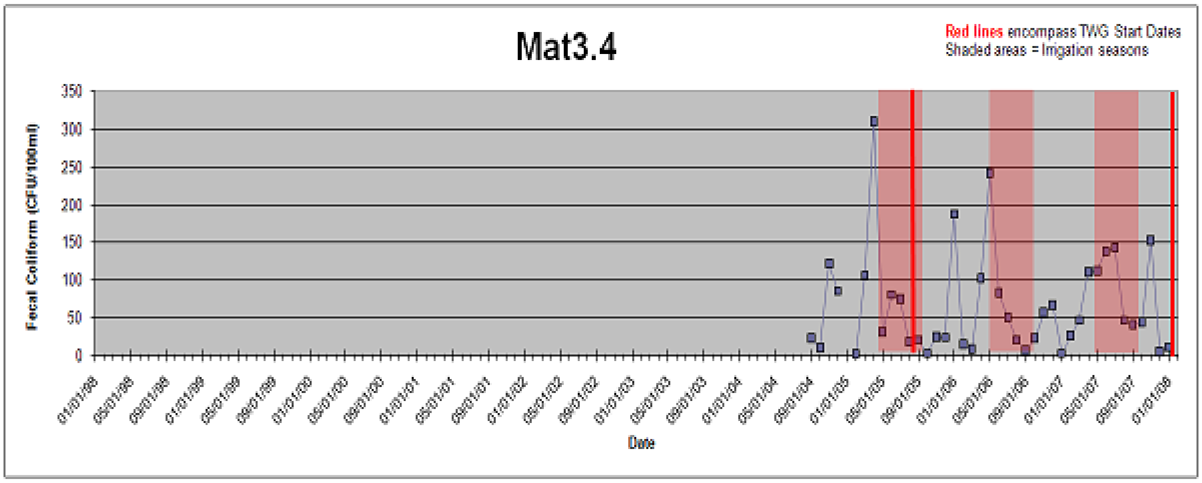
01/01/05
05/01/05
09/01/05
01/01/06
05/01/06
09/01/06
01/01/07
05/01/07
09/01/07
01/01/08
Date


Mat3.4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
350
300
250
200
150
100
50
0
01/01/98
05/01/98
09/01/98
01/01/99
05/01/99
09/01/99
01/01/00
05/01/00
09/01/00
01/01/01
05/01/01
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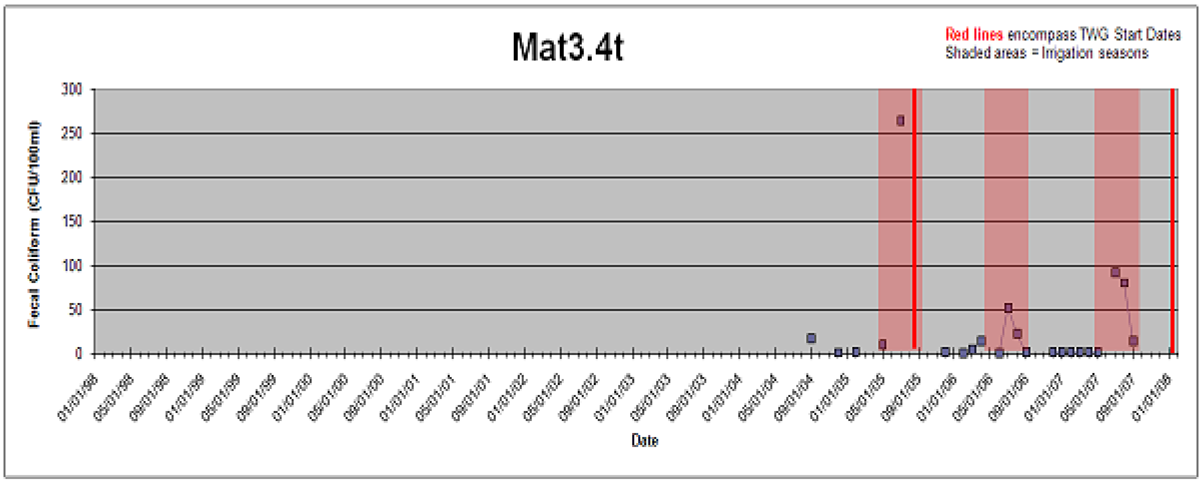
05/01/05
09/01/05
01/01/06
05/01/06
09/01/06
01/01/07
05/01/07
09/01/07
01/01/08
Date


Mat3.4t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
300
250
200
150
100
50
0
01/01/98
05/01/98
09/01/98
01/01/99
05/01/99
09/01/99
01/01/00
05/01/00
09/01/00
01/01/01
05/01/01
09/01/01
01/01/02
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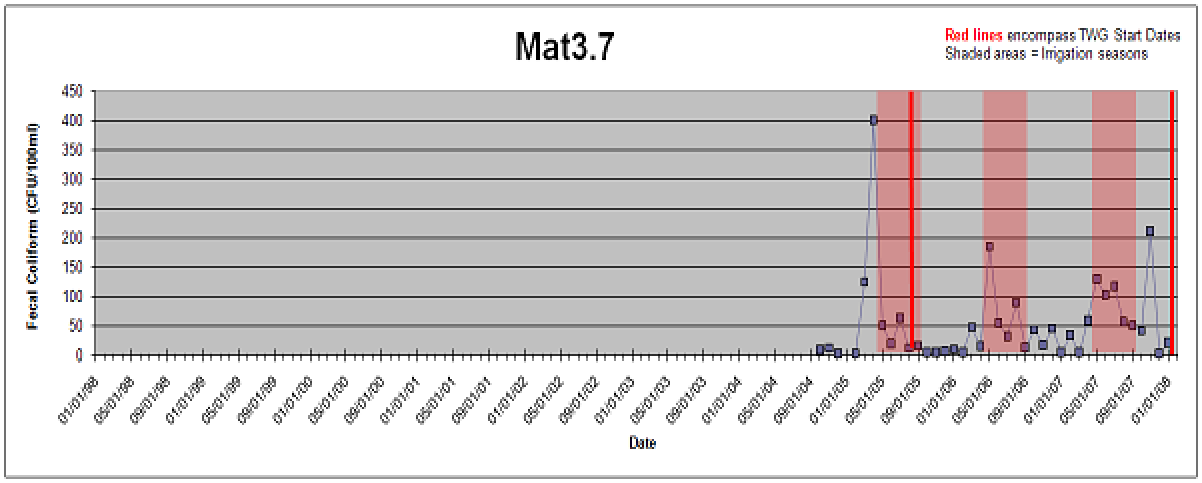
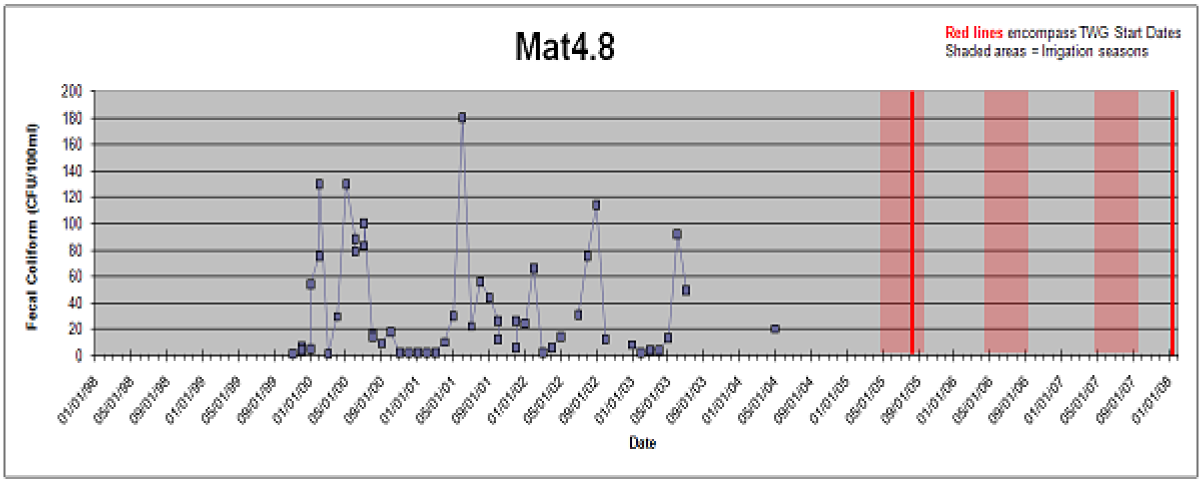
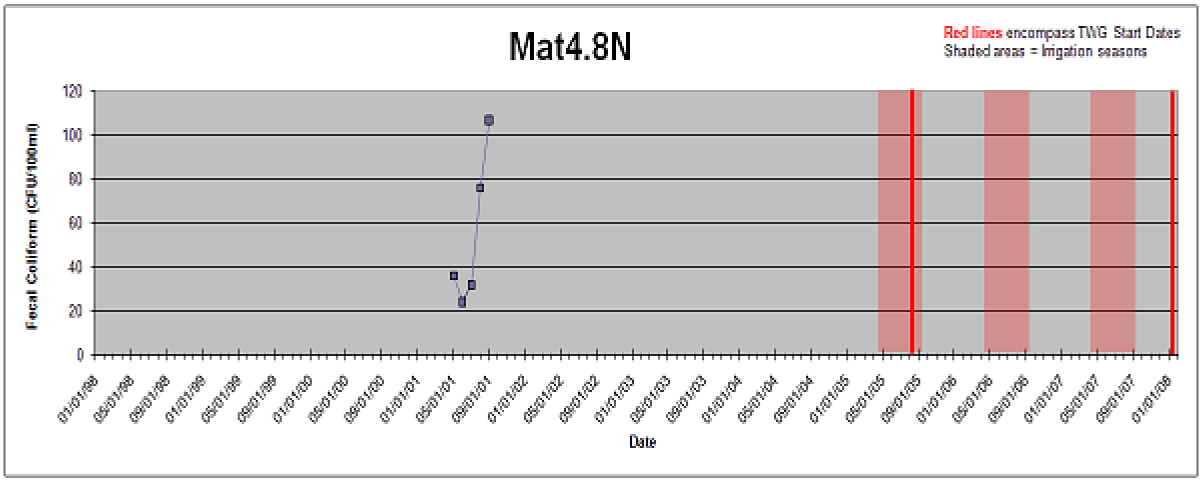
05/01/05
09/01/05
01/01/06
05/01/06
09/01/06
01/01/07
05/01/07
09/01/07
01/01/08
Date



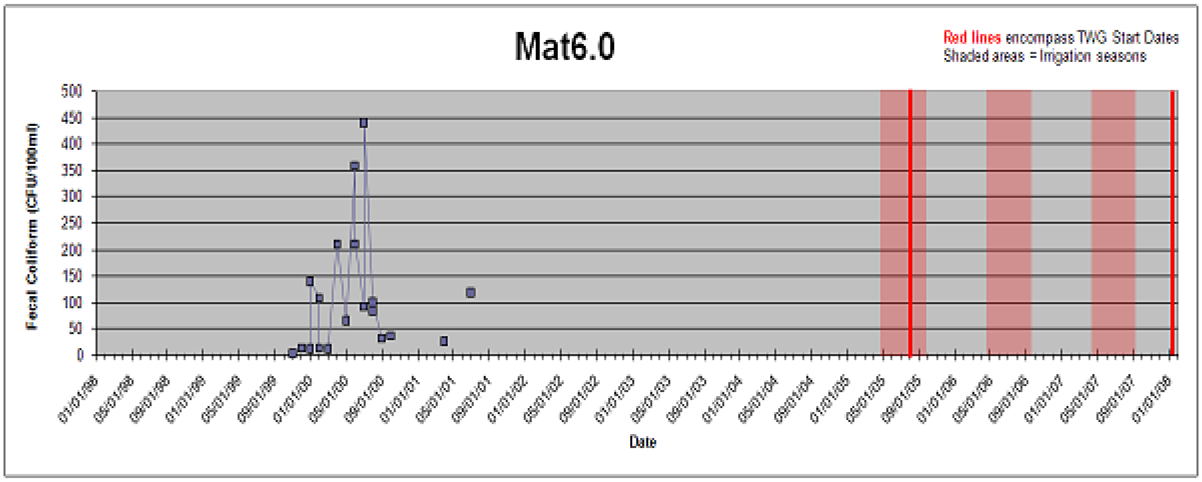
Mat3.7
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

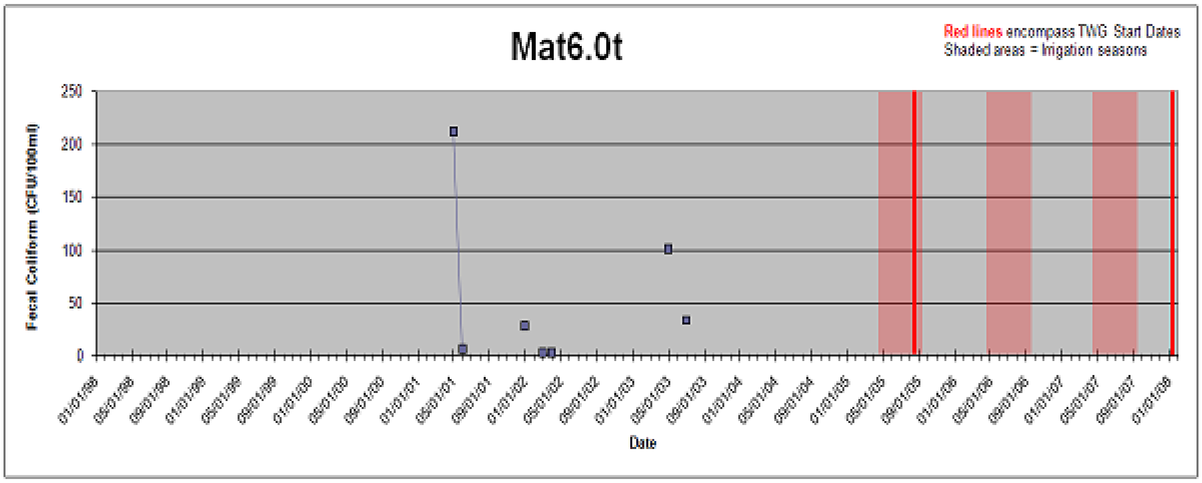


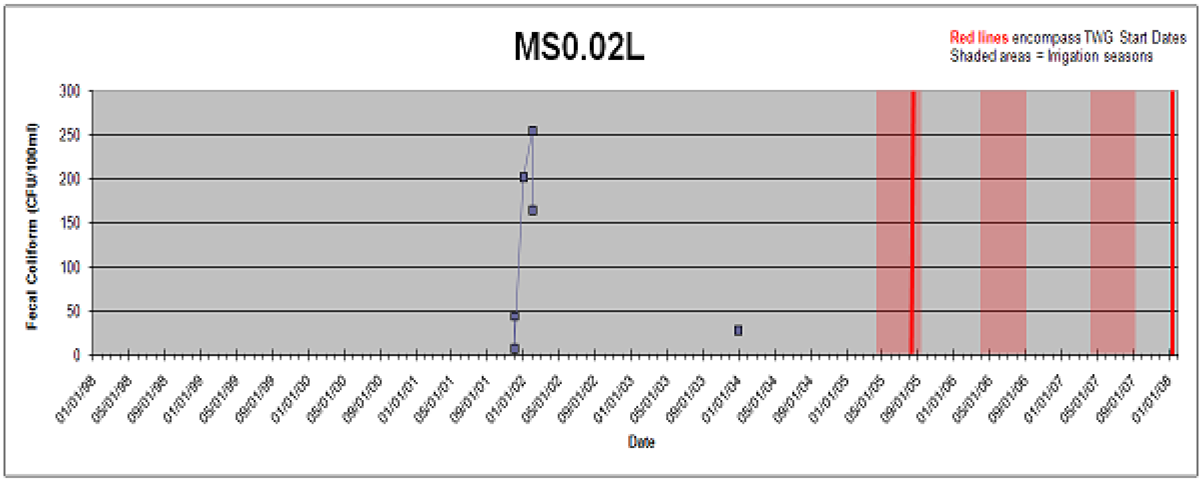
Mat4.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

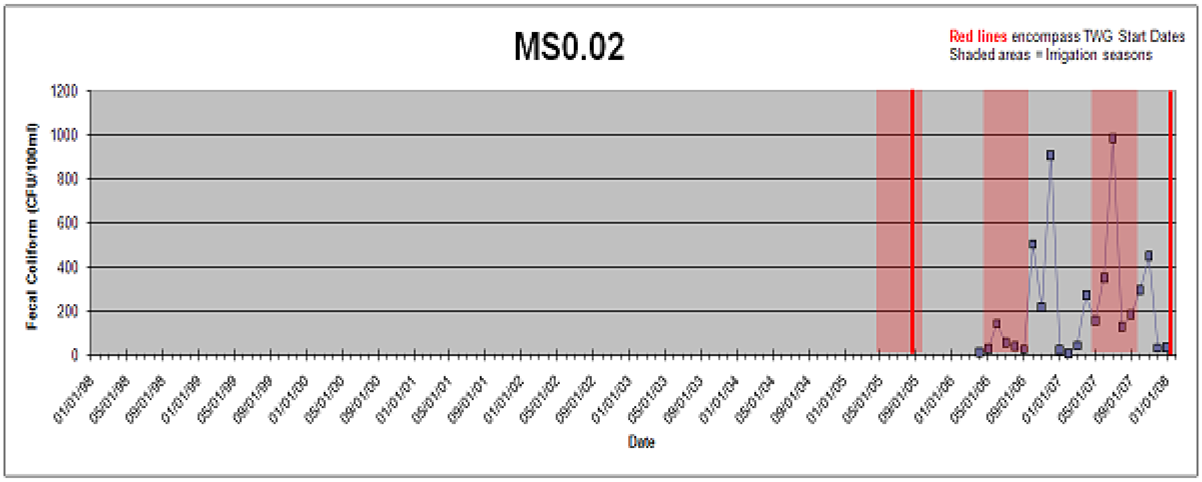


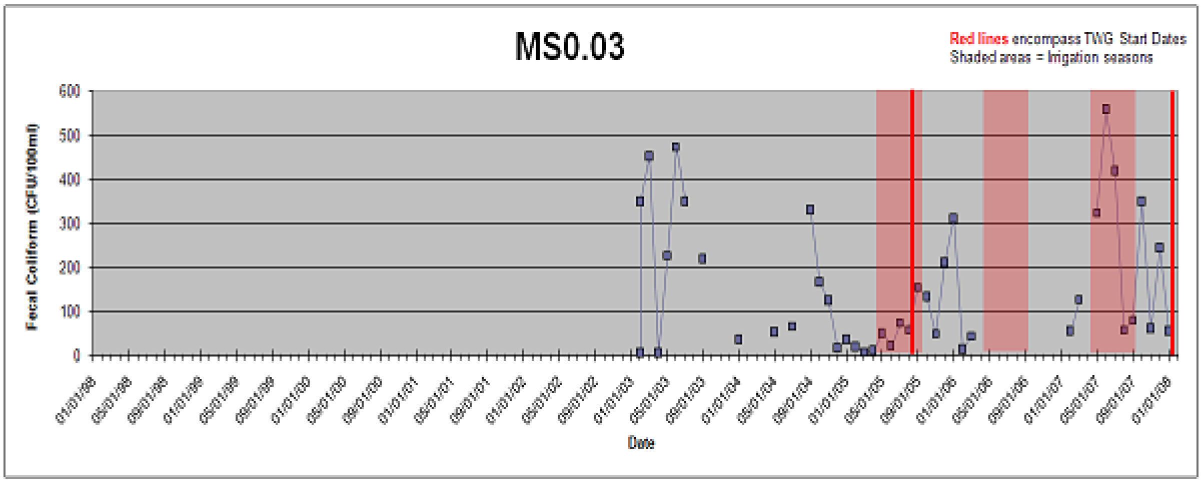
Mat4.8N
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

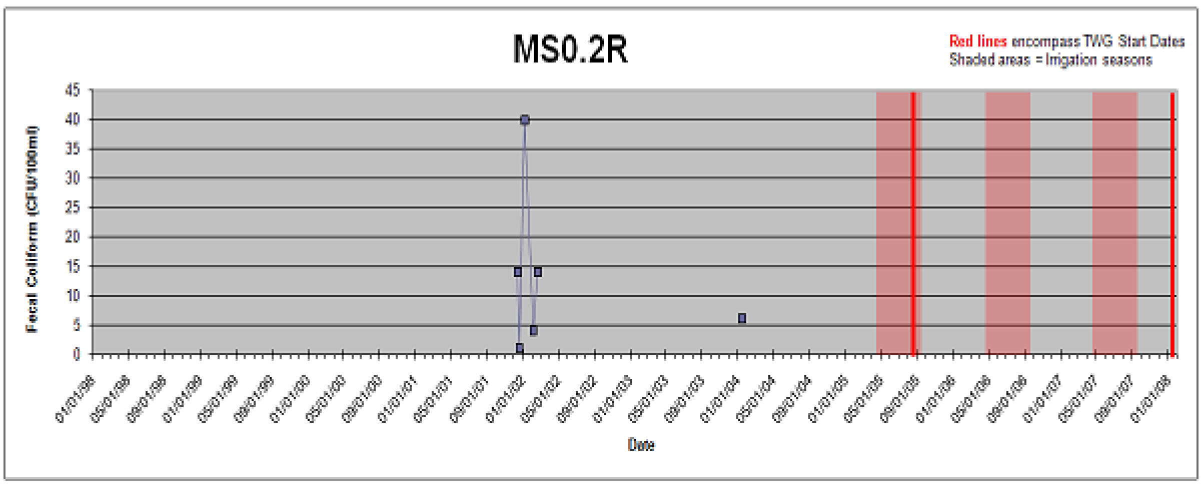

Mat6.0
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

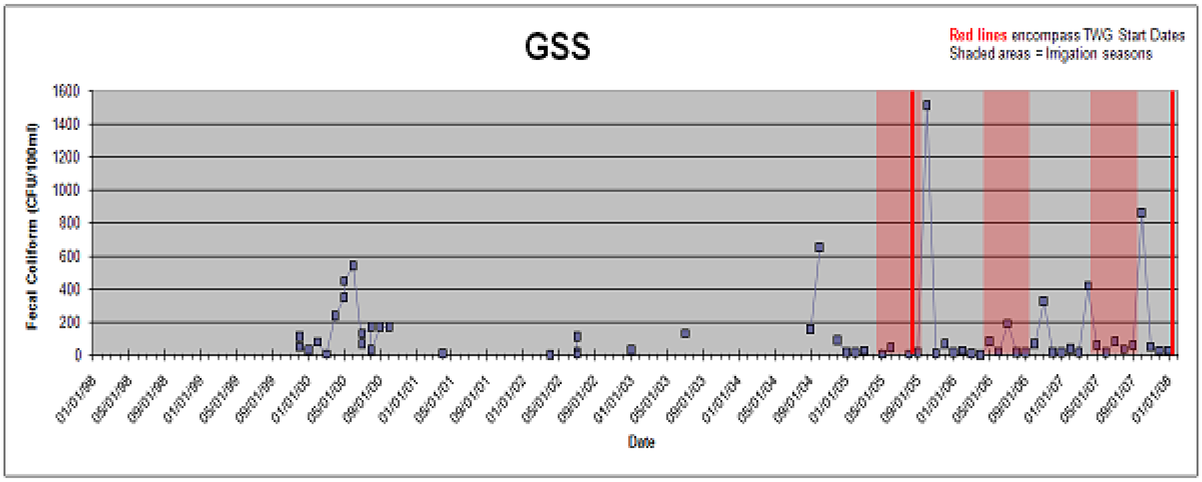

Mat6.0t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

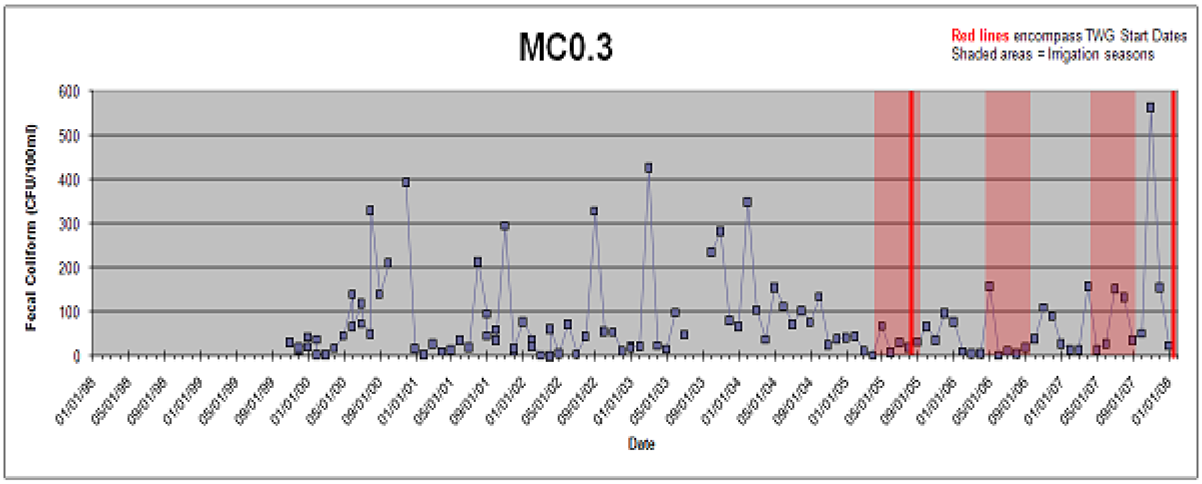

MS0.02L
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

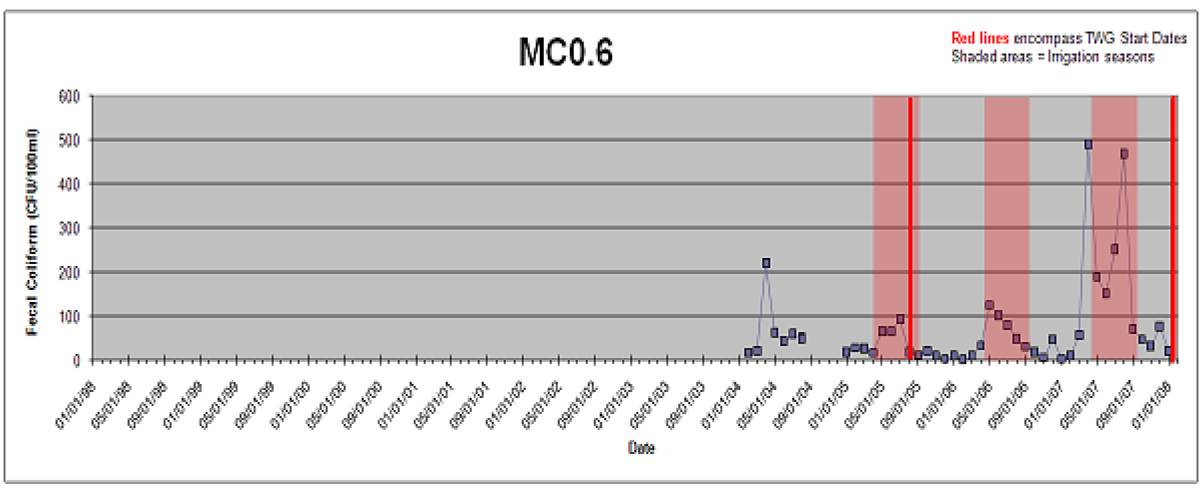

MS0.02
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

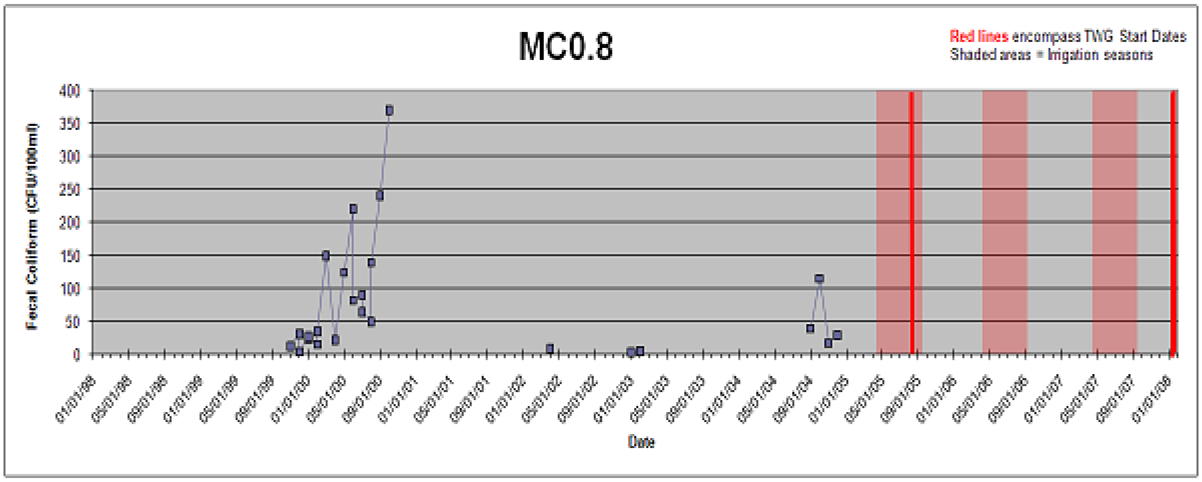

MS0.03
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

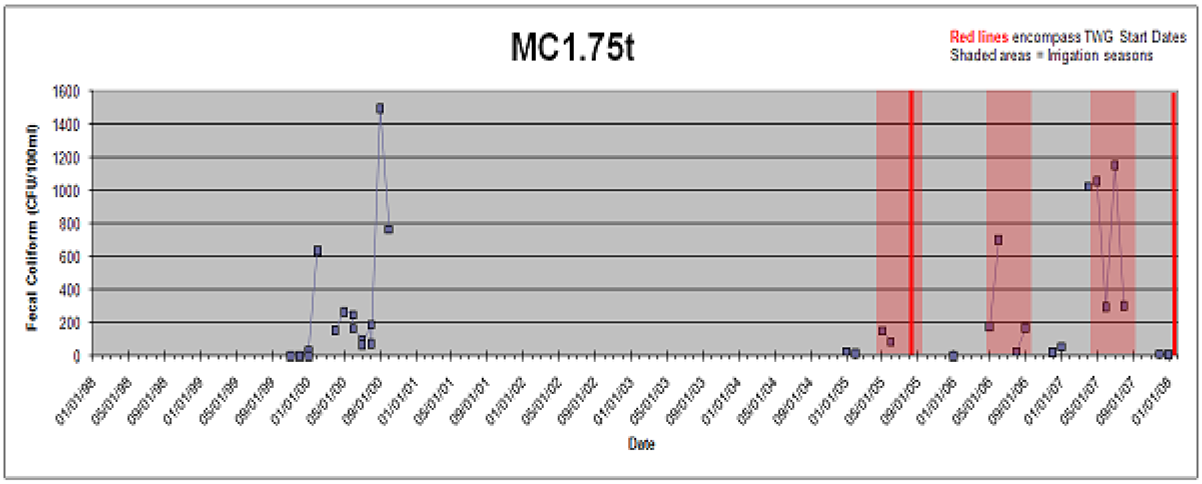

MS0.2R
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

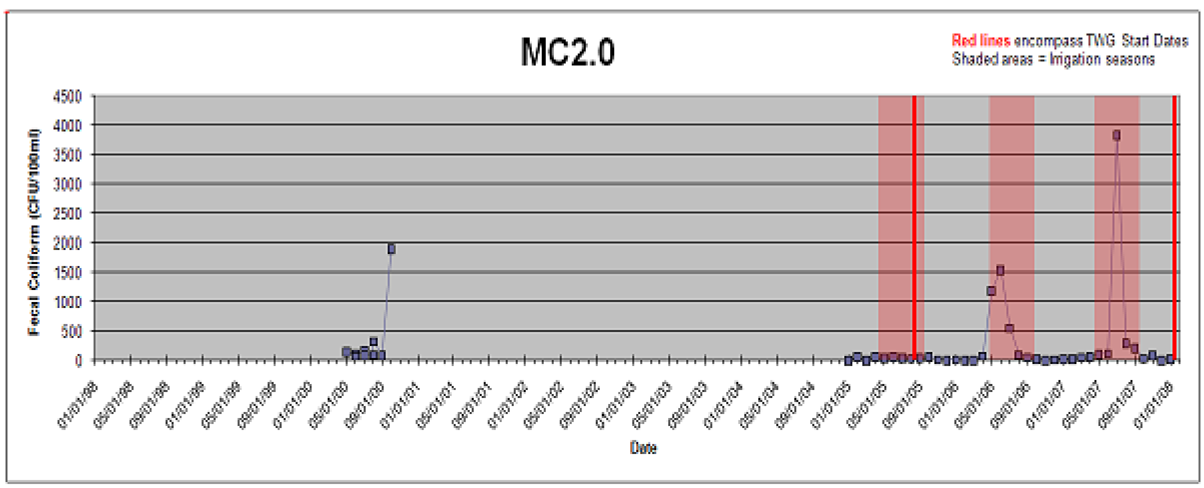

GSS
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
1600
1400
1200
1000
800
600
400
200
0
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

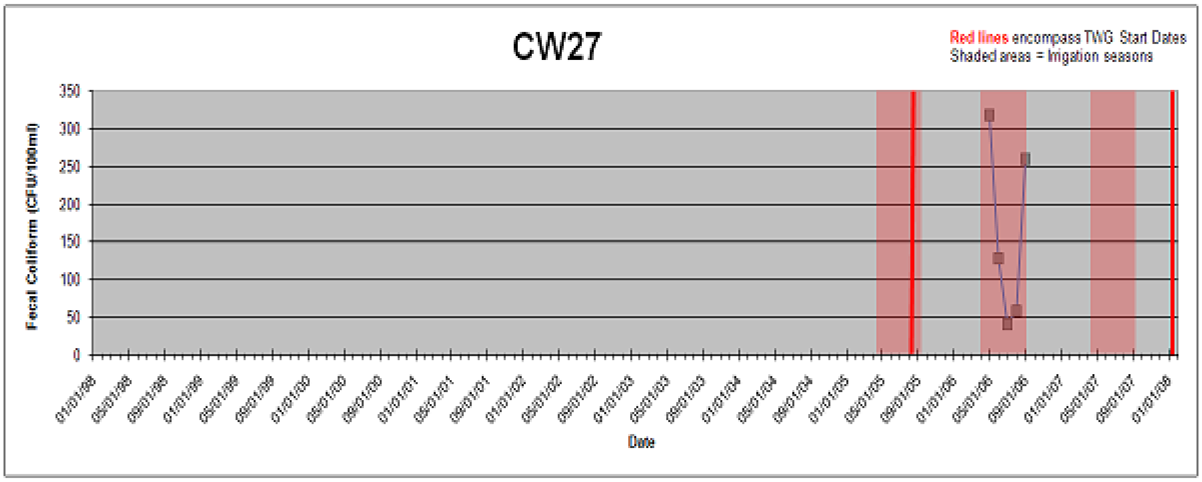

MC0.3
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
600
500
400
300
200
100
0
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

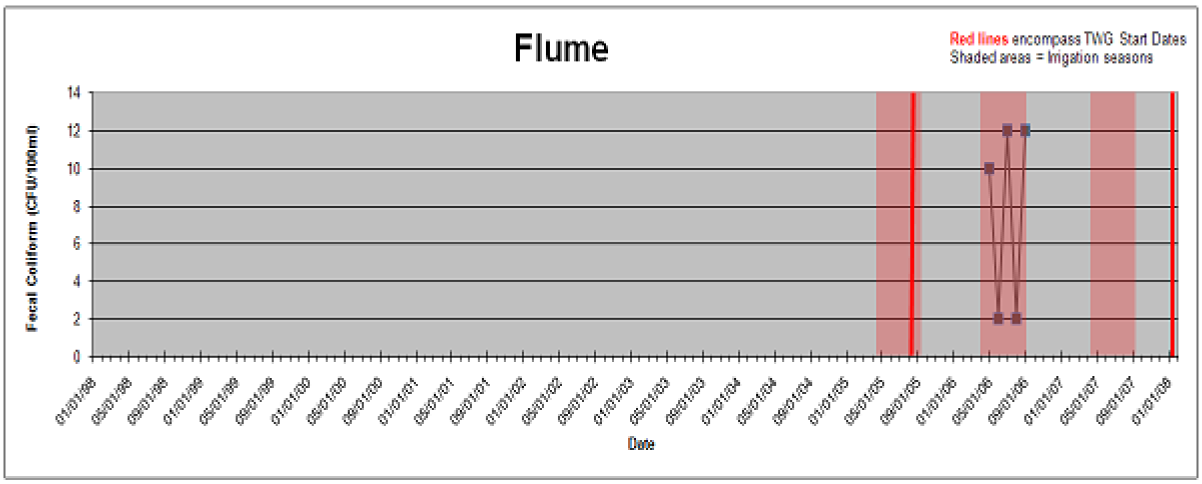

MC0.6
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
600
500
400
300
200
100
0
01/01/98 05/01/98 09/01/98 01/01/99 05/01/99 09/01/99 01/01/00 05/01/00 09/01/00 01/01/01 05/01/01 09/01/01 01/01/02 05/01/02 09/01/02 01/01/03 05/01/03 09/01/03 01/01/04 05/01/04 09/01/04 01/01/05 05/01/05 09/01/05 01/01/06 05/01/06 09/01/06 01/01/07 05/01/07 09/01/07 01/01/08
Date

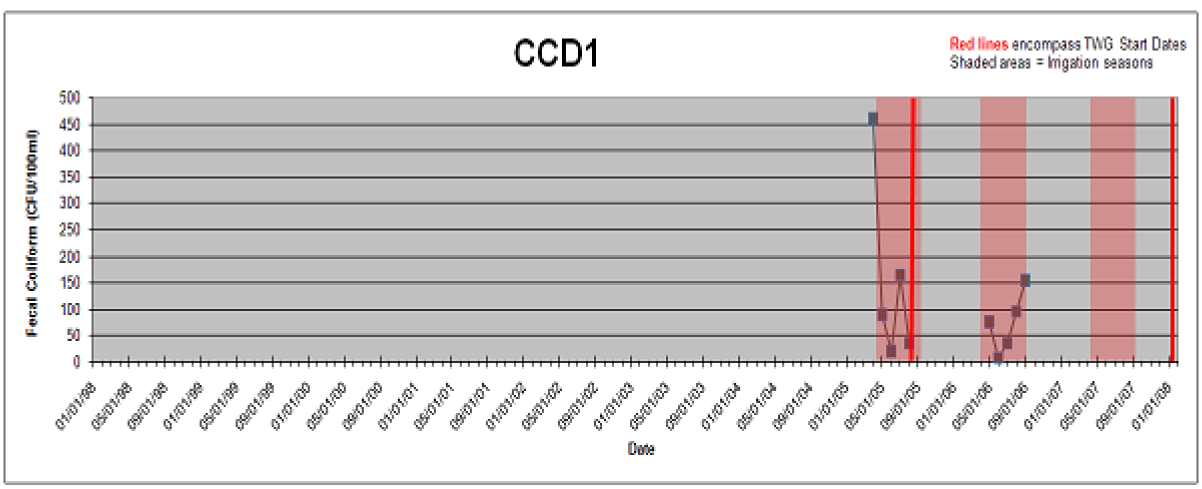

MC0.8
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

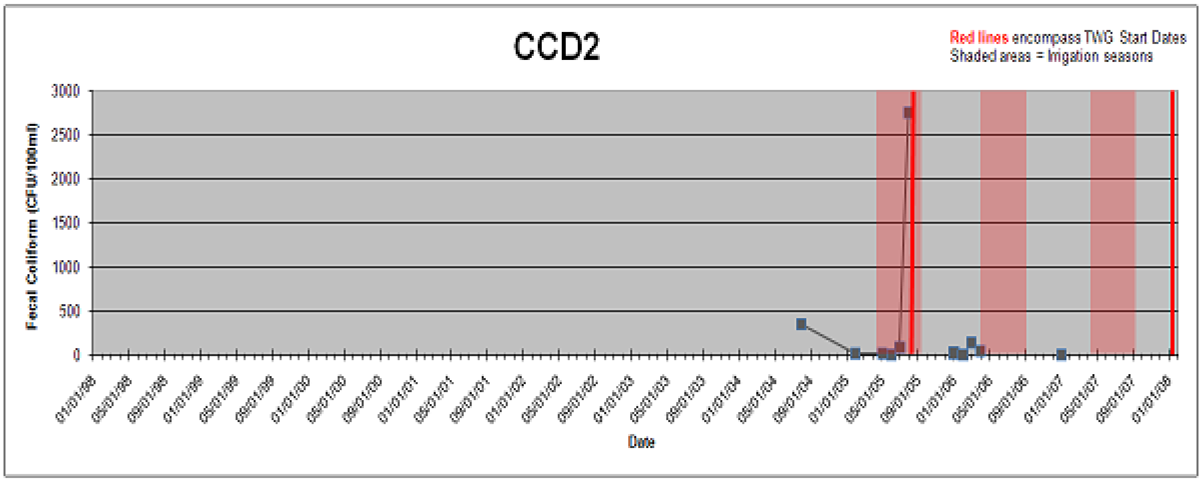

MC1.75t
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

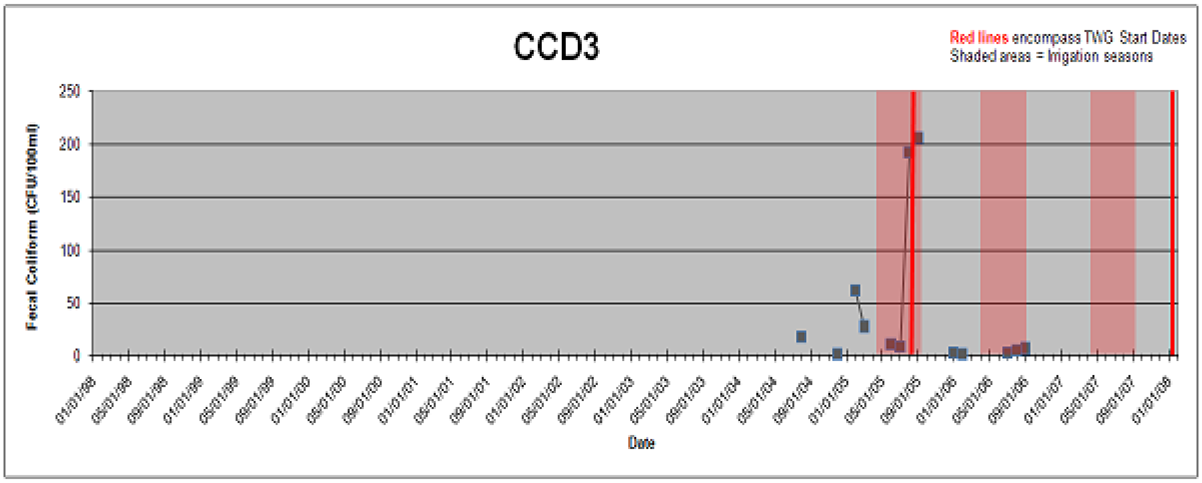

MC2.0
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

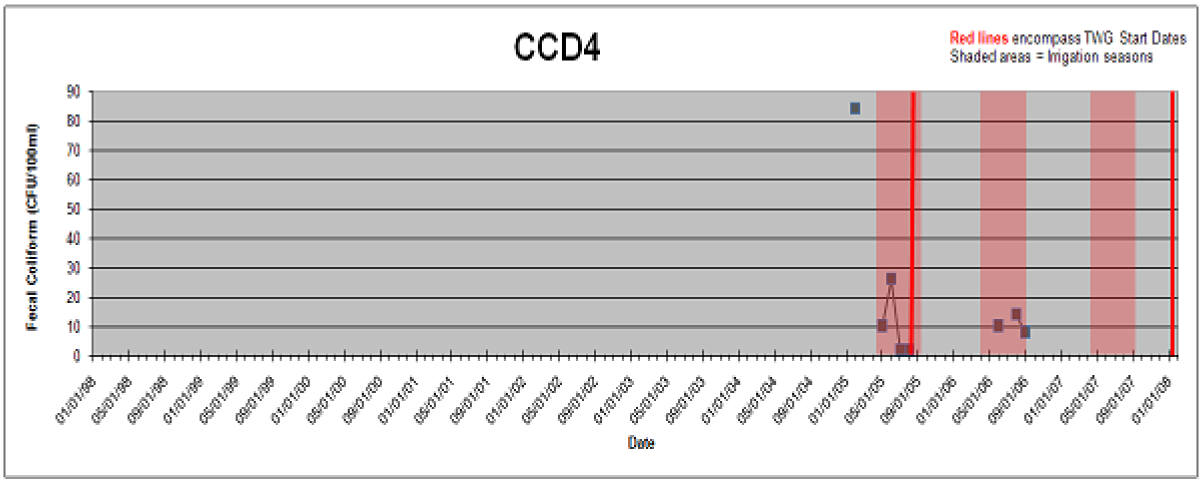

CW27
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
50
100
150
200
250
300
350
Date

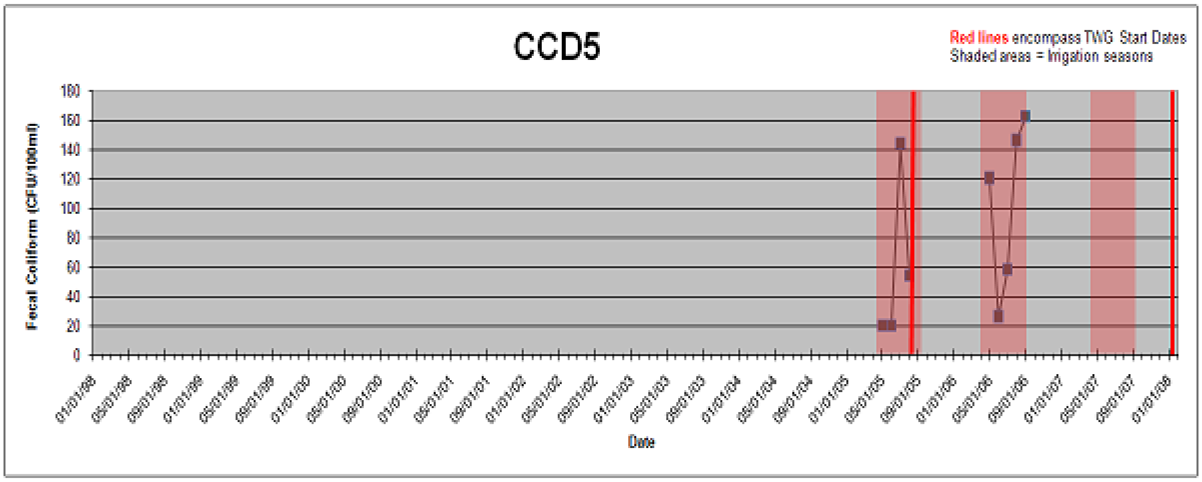

Flume
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
2
4
6
8
10
12
14
Date

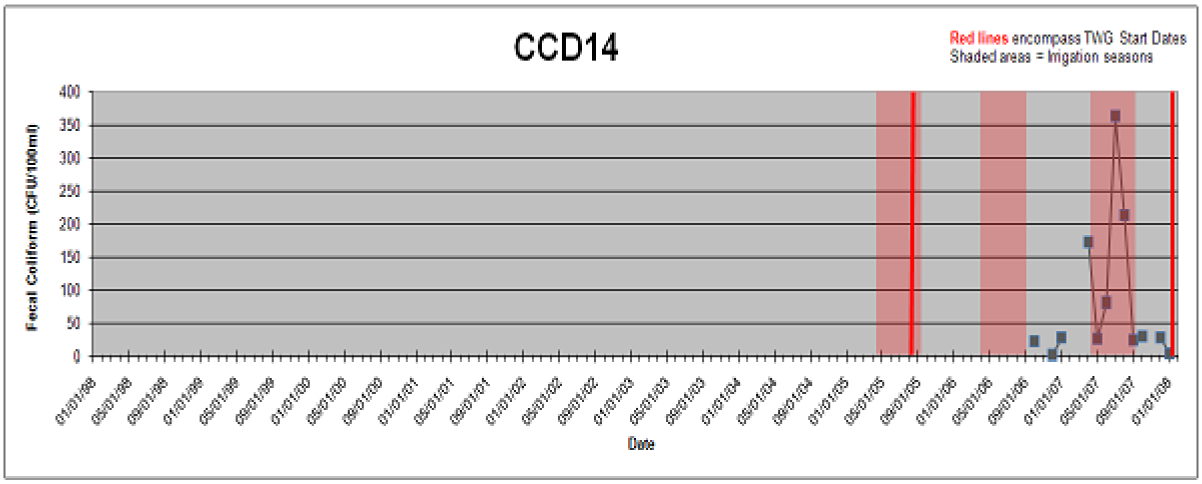

CCD1
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
50
100
150
200
250
300
350
400
450
500
Date

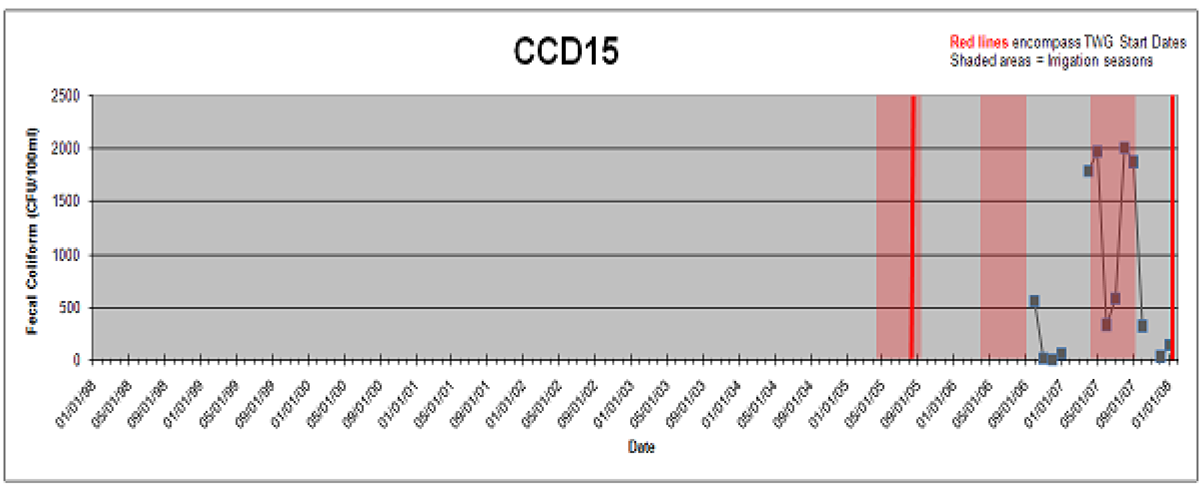

CCD2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

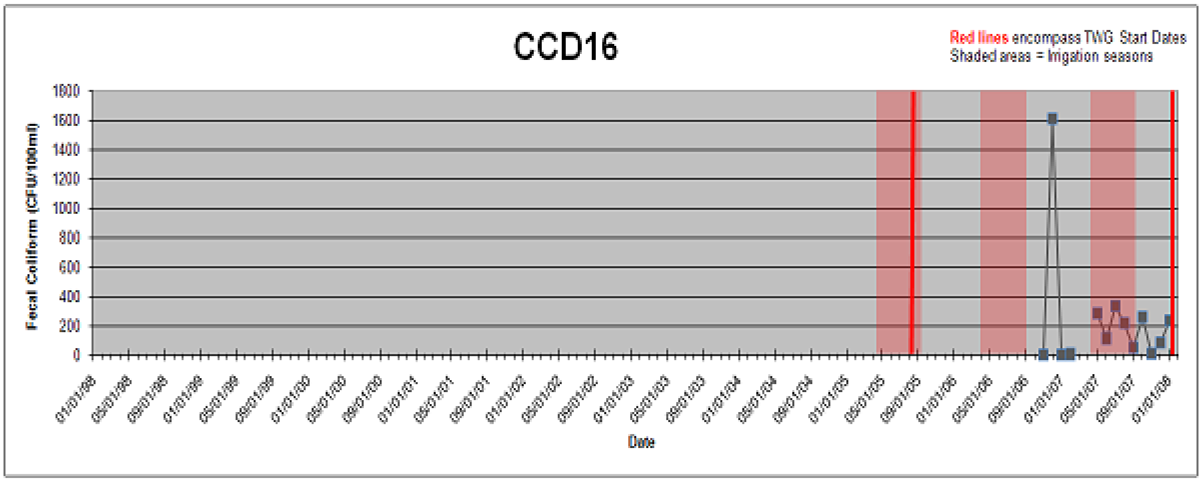

CCD3
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

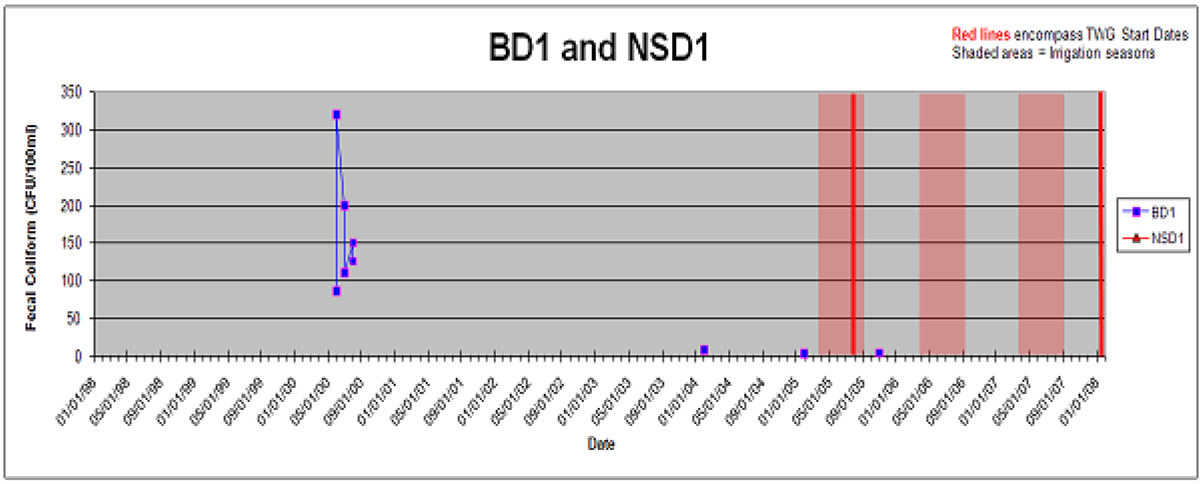

CCD4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

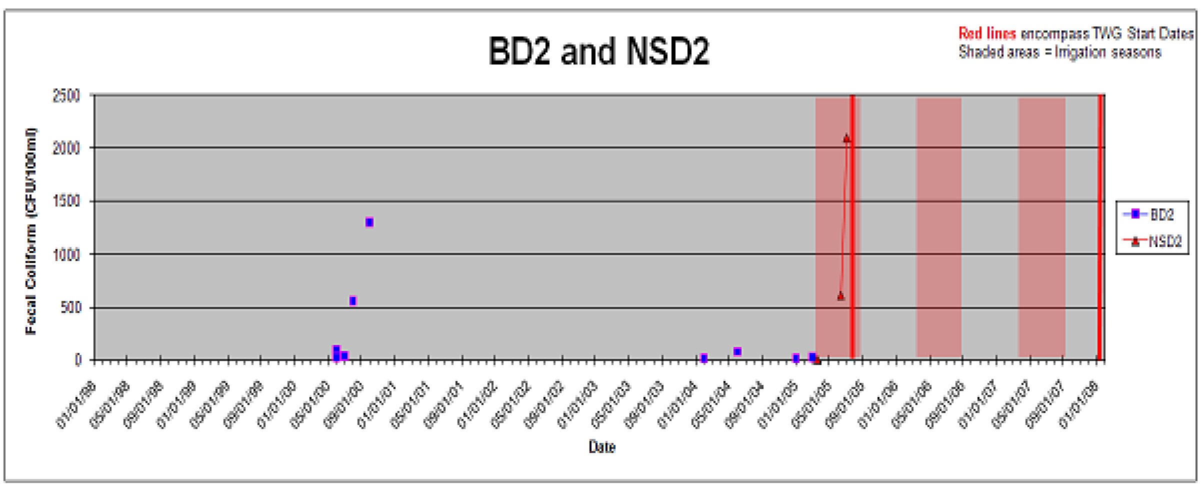

CCD5
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
20
40
60
80
100
120
140
160
180
Date

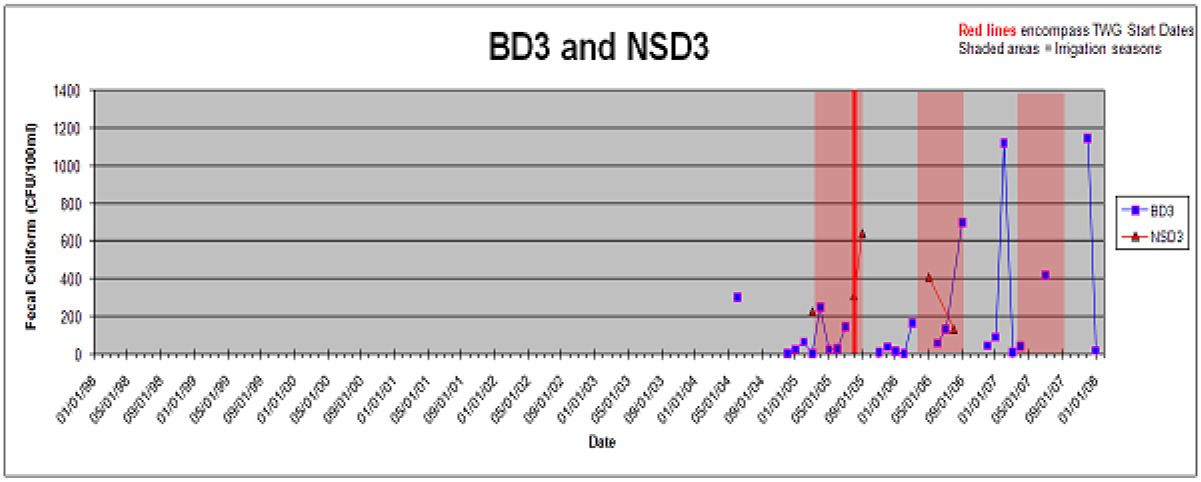

CCD14
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
50
100
150
200
250
300
350
400
Date

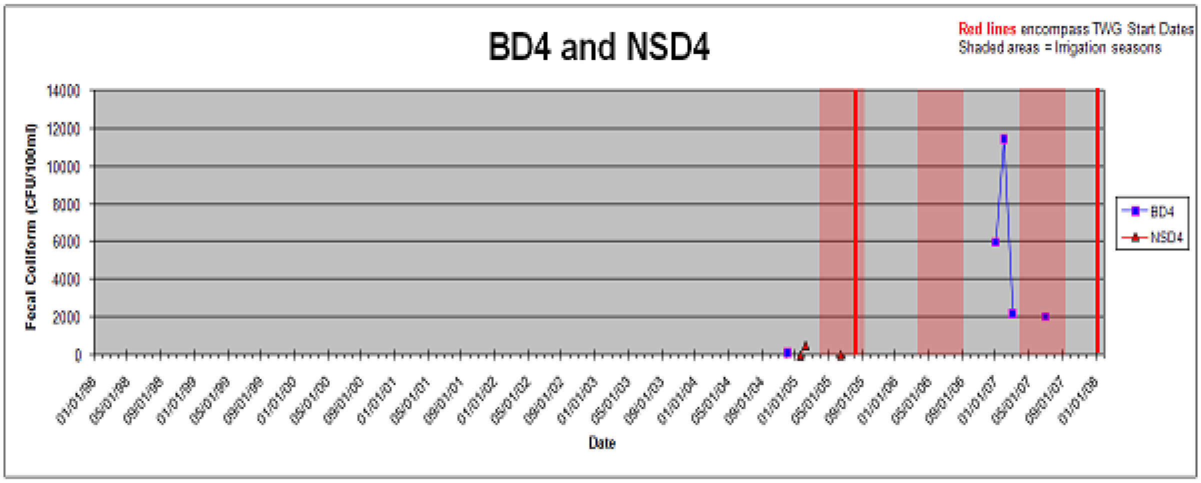

CCD15
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
0
500
1000
1500
2000
2500
Date

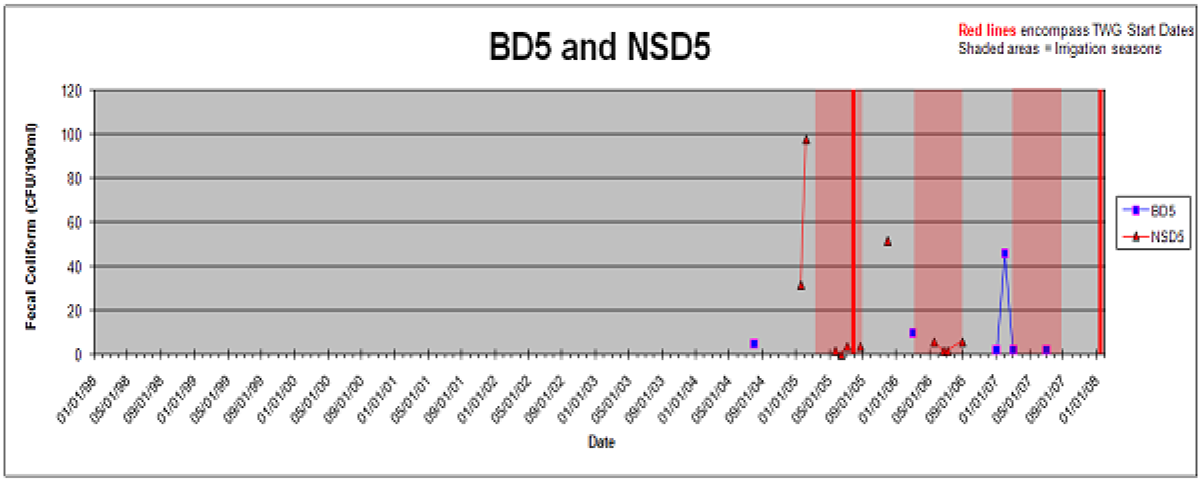

CCD16
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date

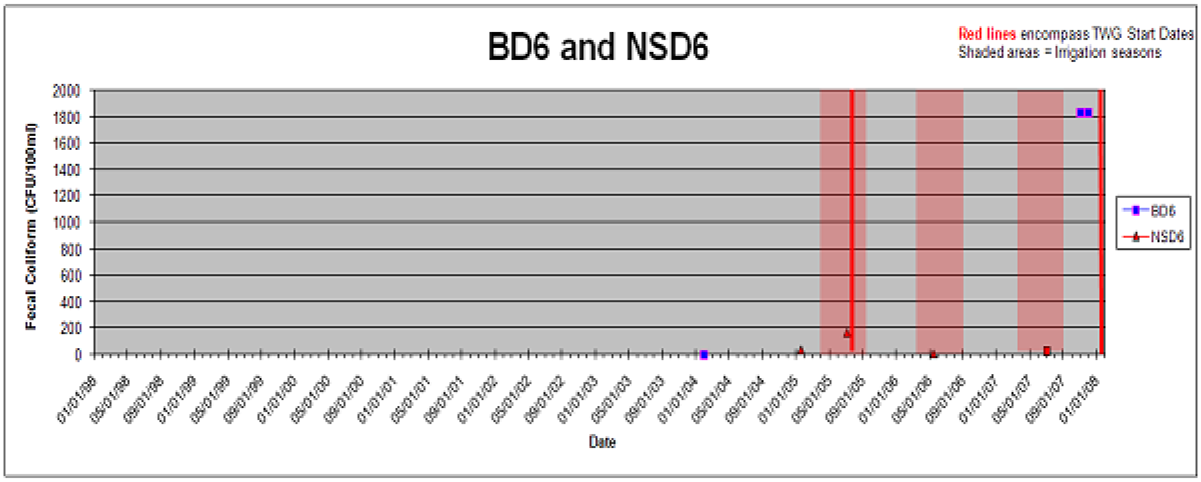

BD1 and NSD1
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
BD1
NSD1
Date

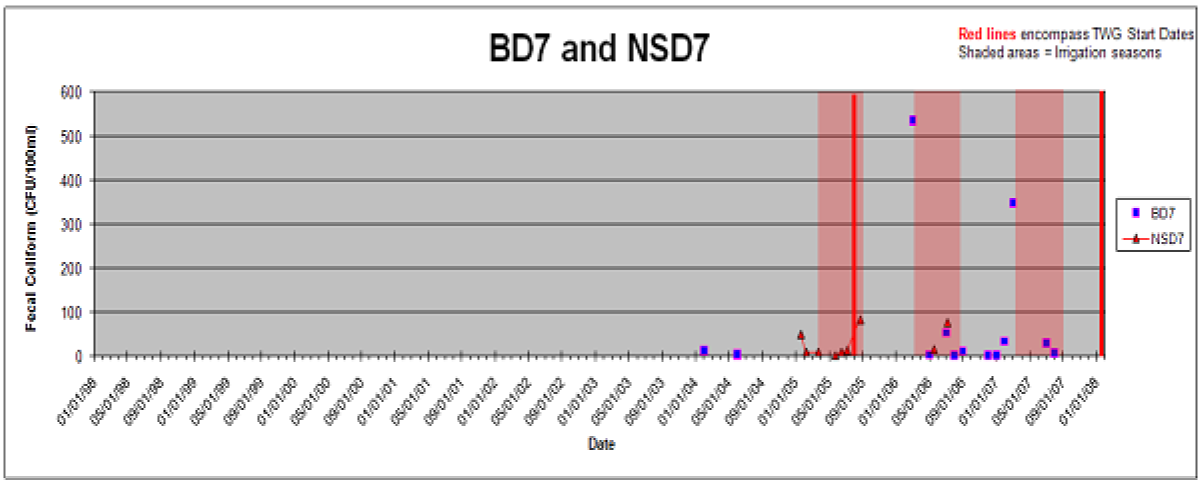

BD2 and NSD2
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
BD2
NSD2
Date


BD3 and NSD3
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date
BD3
NSD3


BD4 and NSD4
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date
BD4
NSD4


BD5 and NSD5
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
Date
BD5
NSD5


BD6 and NSD6
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
01/01/98
05/01/98
09/01/98
01/01/99
05/01/99
09/01/99
01/01/00
05/01/00
09/01/00
01/01/01
05/01/01
09/01/01
01/01/02
05/01/02
09/01/02
01/01/03
05/01/03
09/01/03
01/01/04
05/01/04
09/01/04
01/01/05
05/01/05
09/01/05
01/01/06
05/01/06
09/01/06
01/01/07
05/01/07
09/01/07
01/01/08
Date
BD6
NSD6


BD7 and NSD7
Red lines encompass TWG Start Dates
Shaded areas = Irrigation seasons
Fecal Coliform (CFU/100ml)
600
500
400
300
200
100
0
01/01/98
05/01/98
09/01/98
01/01/99
05/01/99
09/01/99
01/01/00
05/01/00
09/01/00
01/01/01
05/01/01
09/01/01
01/01/02
05/01/02
09/01/02
01/01/03
05/01/03
09/01/03
01/01/04
05/01/04
09/01/04
01/01/05
05/01/05
09/01/05
01/01/06
05/01/06
09/01/06
01/01/07
05/01/07
09/01/07
01/01/08
Date
BD7
NSD7