Appendix G
Bacteria Data Review

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LONGITUDINAL AND SEASONAL ANALYSIS

PUDDING RIVER

A review of Pudding River bacteria data from sites arranged longitudinally, i.e. plotted from stream headwaters to mouth (Figure G- 1), indicates that tributaries to the Pudding River may be contributing to bacteria criteria exceedances measured in the Pudding River. However, the longitudinal plot does not indicate one or more distinct source of bacteria. The same data split into summer months (June – September) and winter months (October – May) is illustrated in Figure G- 2 and Figure G- 3. Not all samples were collected at the same time, so the longitudinal plots are not "snapshot" views. Still, available data suggest that all the tributaries except Abiqua Creek may enter the Pudding River with higher median bacteria concentrations than the mainstem in both winter and summer months. How much influence each tributary has on mainstem Pudding River concentrations will depend on bacteria concentrations and the percent of flow the tributary contributes to the mainstem. Silver and Butte Creeks, based on annual average streamflow[1], contribute approximately 30% and 17%, respectively, of the Pudding River stream flow where they enter. Mill Creek (4%) and Zollner Creek (3%)[2] on average contribute relatively less to the Pudding River mainstem flow based on annual average flow calculations. Insufficient flow measurements are available to calculate the average flow contribution from the Little Pudding River to the mainstem Pudding River.

Among the four lower sites with the largest data sets (the sites between approximate river miles 5 and 25 on the Pudding River - Figure G- 1- Figure G- 3), interquartile ranges (between the 25th and 75th percentiles) are similar. With the exception of the lowest site (river mile 4.4 at Arndt Rd.), median concentrations tend to be near or below the 126 log mean criterion, but at most sites the 75th percentiles of the year-round data sets exceed the 126 log mean criterion. The apparently higher median concentration in samples collected from river mile 4.4 (Arndt Road) may reflect a smaller data set or change in land use since the Ardnt Road measurements were collected (1969 – 1975), not necessarily an increase in mainstem bacteria concentrations. Sample sets from sites upstream of river mile 26 are too small to draw any conclusions about longitudinal variation.

[1] Oregon Water Resources Department Consumptive Use report: http://map.wrd.state.or.us/apps/wr/wr_mapping/

[2] USGS annual average flow based on available records: http://wdr.water.usgs.gov/

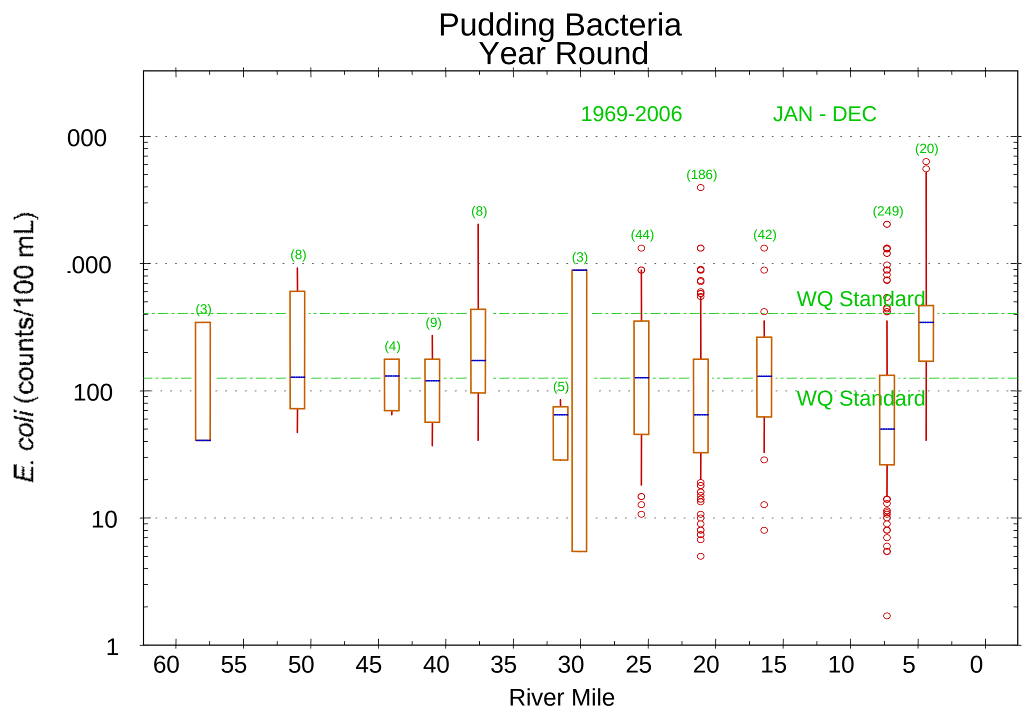

Figure G- 1: Distribution of bacterial concentrations measured year-round along the Pudding River. Fecal coliform data have been converted to equivalent *E. coli* counts. Horizontal lines indicate the two numeric *E. coli* bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

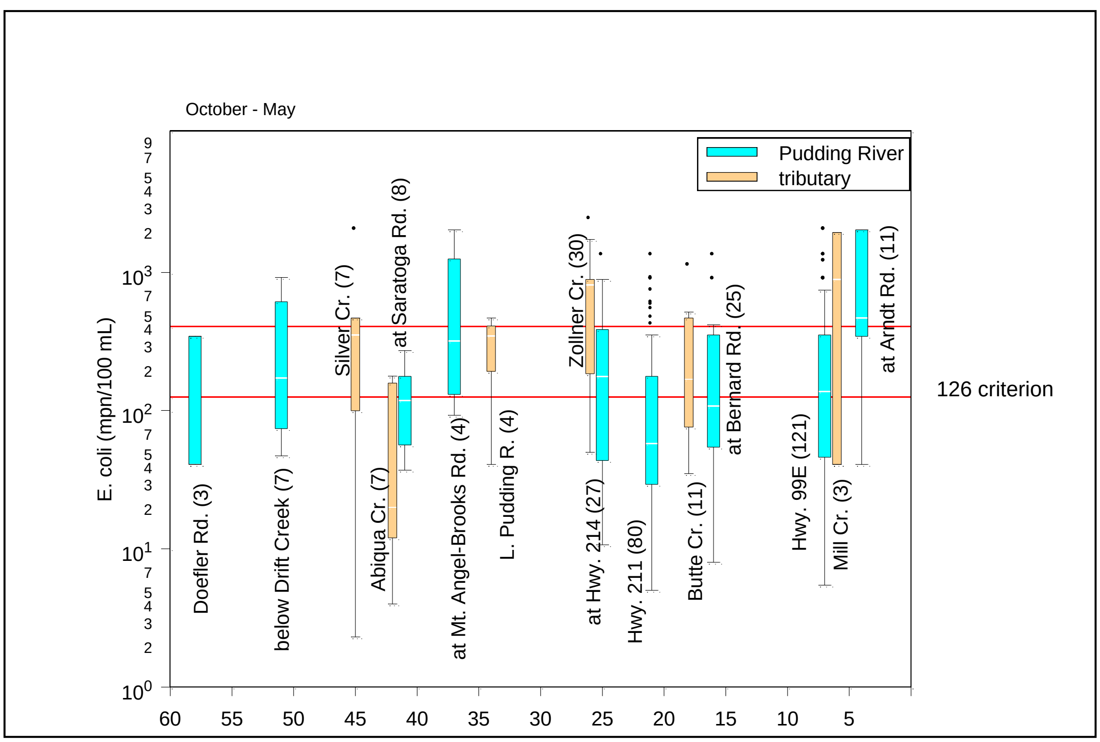

Figure G- 2: Pudding River and tributary bacteria concentration distributions measured in winter months (October – May) 1969 - 2006.
Fecal coliform data have been converted to equivalent *E. coli* counts. Horizontal lines indicate the two numeric *E. coli* bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

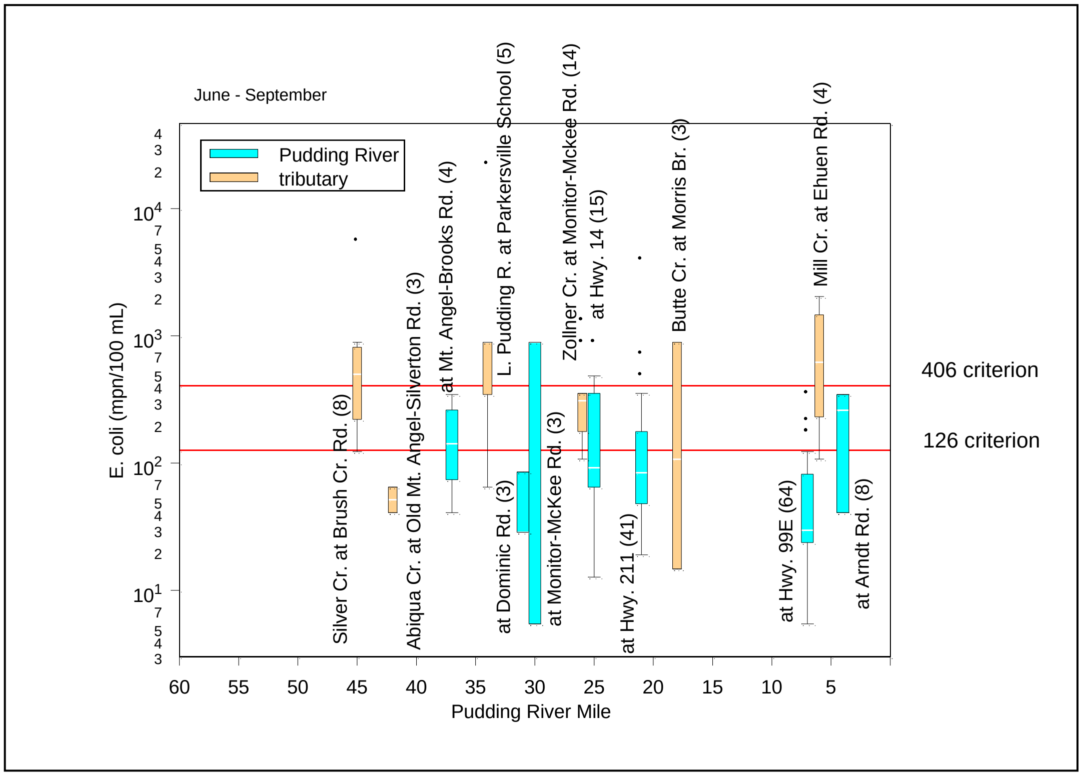

Figure G- 3: Pudding River and tributary bacteria concentration distributions measured in summer months (June - September) 1969 - 2006.
Fecal coliform data have been converted to equivalent *E. coli* counts. Horizontal lines indicate the two numeric *E. coli* bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

DEQ also reviewed data seasonality at the three Pudding River sites with the largest data sets. Figure G- 4 through Figure G- 6 illustrate the quarterly variation in bacterial counts measured at those three sites. The significance of the differences in seasonal medians was evaluated with the WQ Hydro statistical program (Aroner, 1997). The non-parametric Kruskal-Wallis (K-W) test is used for the analysis. The null (H_o) and alternate (H_a) hypotheses for this test are as follows:

> H_o: All groups of data have identical distributions
> H_a: At least one group differs in its distribution

In this form, the only interest in the data is to determine whether all groups are identical, or whether some tend to contain observations different in value than the others. This difference is not attributed solely to a difference in median, though this is one possibility (Helsel and Hirsch, 2002).

For the lower two Pudding River sites with large amounts of data, Highway 99E (river mile 7.3) and Highway 211 (river mile 21) the K-W test indicates that we can reject the null hypothesis of identical distributions and conclude that there are seasonal differences. The confidence level that at least one of the seasons differs from the others is greater (99%) at the lower site (Highway 99E) than at the Highway 211 site (95%). In other words, there is only a 1% chance that there is no seasonality at Highway 99E, but up to a 5% chance that there is no seasonality at Highway 211. The season of greatest median concentration also differs between the two sites, being greatest during the first quarter (January – March) at Highway 99E and greatest during the 3rd quarter (July – September) at the Highway 211 site. This may reflect the influence of discharge from the Woodburn Wastewater Treatment Plant, which discharges just upstream of the Highway 211 site.

At the furthest upstream site of the three (Highway 214, river mile 25.5), the seasonal signature is reduced and not considered significant. This site is approximately four river miles upstream from the Highway 211 site and upstream of the major portion of developed Woodburn. The apparent difference in seasonality with distance upstream may reflect the smaller sample size at the most upstream site, but may also indicate less influence from point source discharge and stormwater.

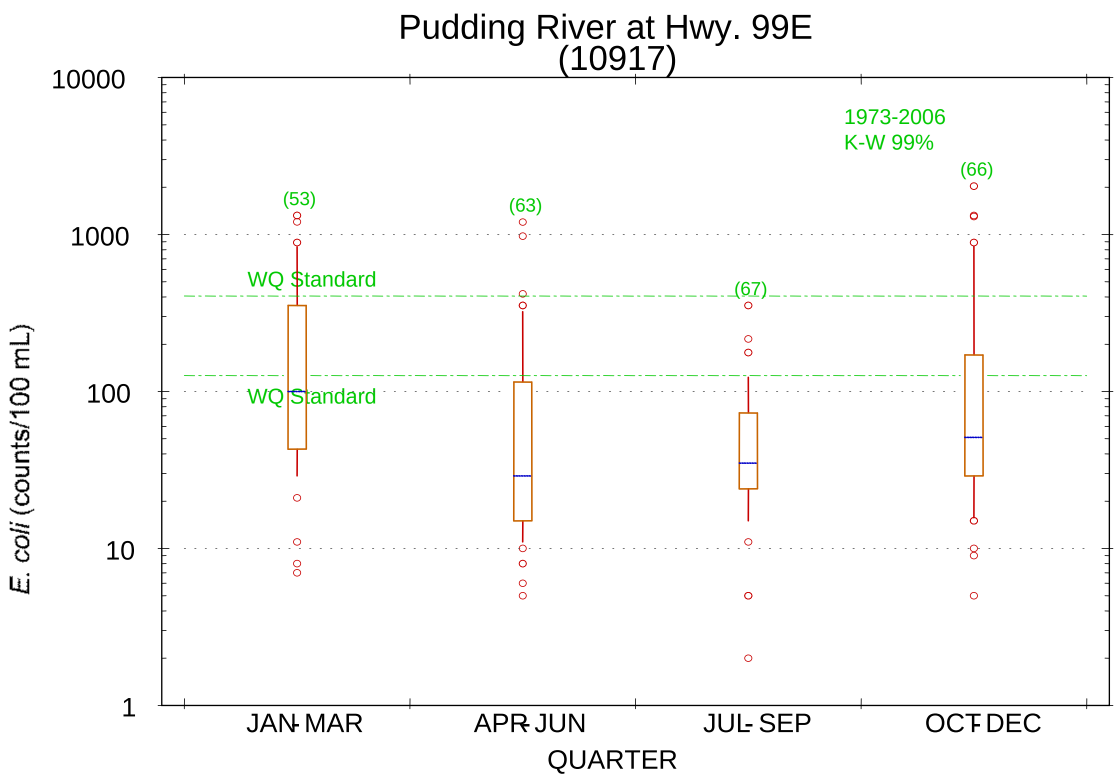

Figure G- 4: Quarterly variation in bacterial counts measured in the Pudding River at Highway 99E, river mile 7.3.
At least one of the quarterly medians is significantly different from the others with a certainty of 99%.

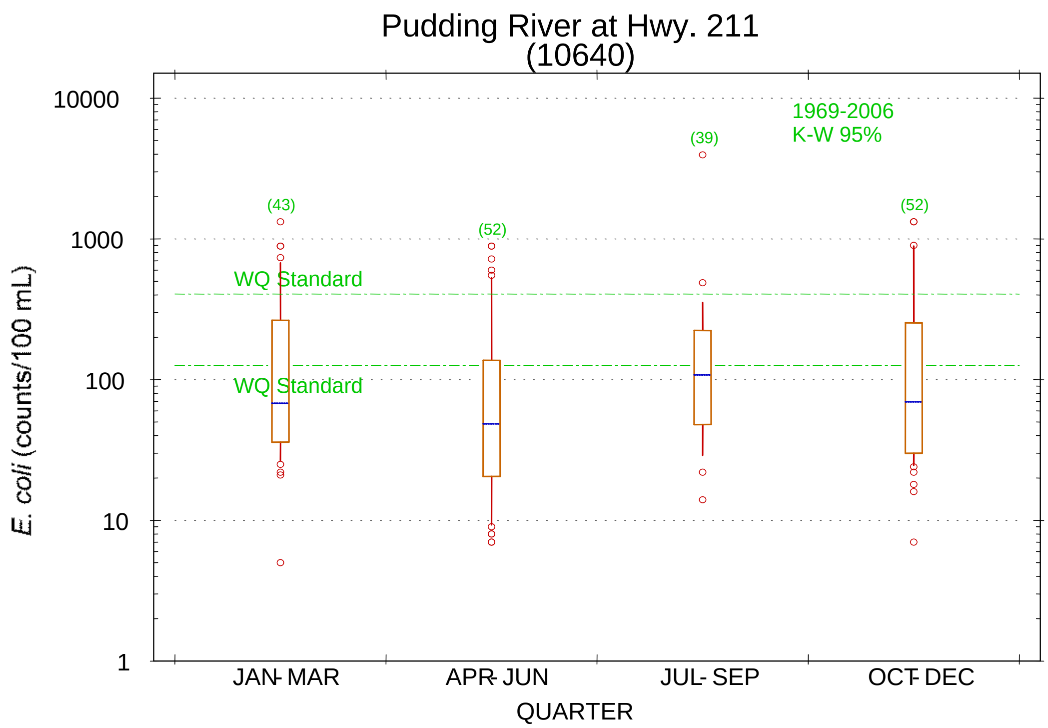

Figure G- 5: Quarterly variation in bacterial counts measured in the Pudding River at Highway 211, river mile 21.
At least one of the quarterly medians is significantly different from the others with a certainty of 95%.

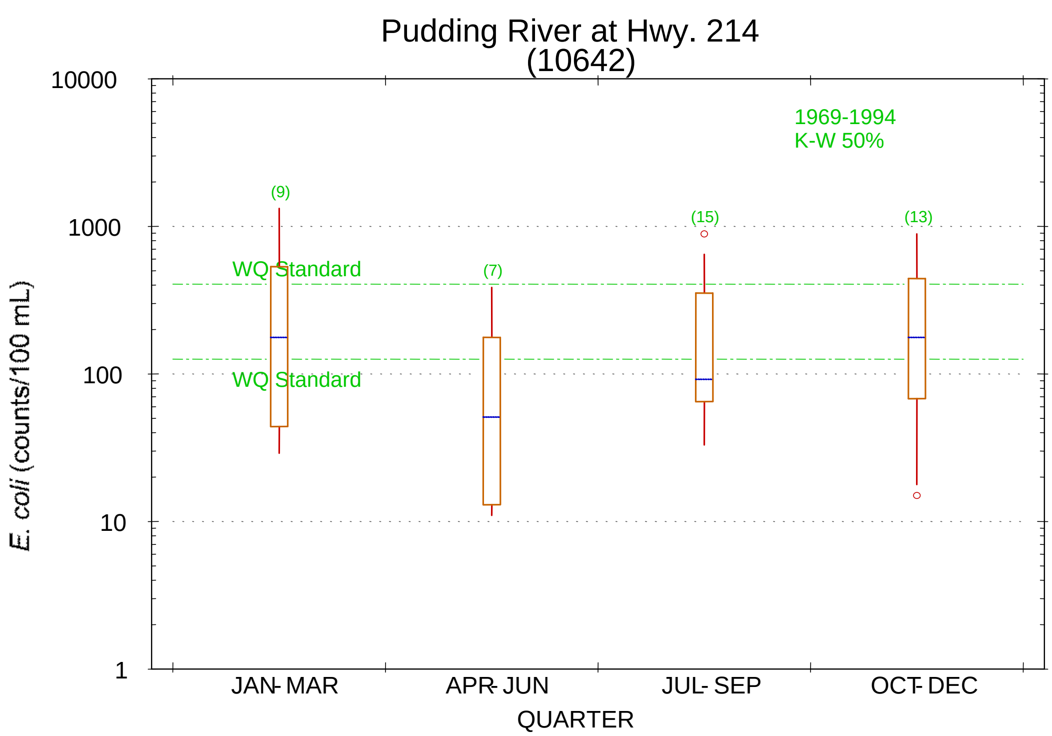

Figure G- 6: Quarterly variation in bacterial counts measured in the Pudding River at Highway 214, river mile 25.5.
The quarterly medians do not differ significantly as the likelihood of a difference is only 50%.

For Zollner Creek bacteria data, the confidence level that at least one of the seasons differs from the others is only 50%, as shown by Figure G- 7. This indicates that there is up to a 50% probability that there is no seasonality at this site, based on the available data. A relatively smaller data set may be the reason for the low confidence level at Zollner Creek relative to the Pudding River sites presented above. Therefore, because of the lack of data, DEQ cannot conclude that variations in bacteria concentrations in Zollner Creek are or are not seasonally related.

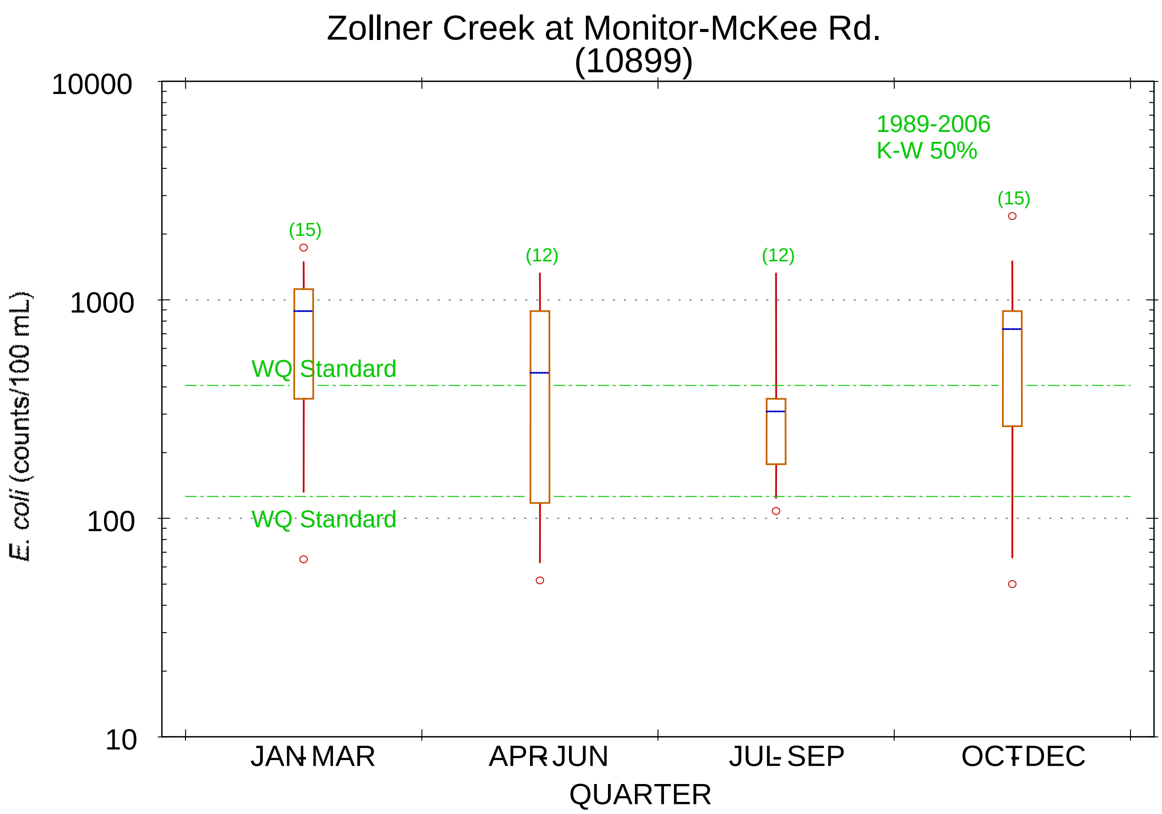

Figure G- 7: Quarterly variation in bacterial counts measured in Zollner Creek.

The Silver Creek data set does not contain sufficient samples in all seasons to make conclusions about seasonality or longitudinal differences (Figure G- 8). Based on available information (Figure G- 9), concentrations measured in the third and fourth quarters in Silver Creek do not differ significantly.

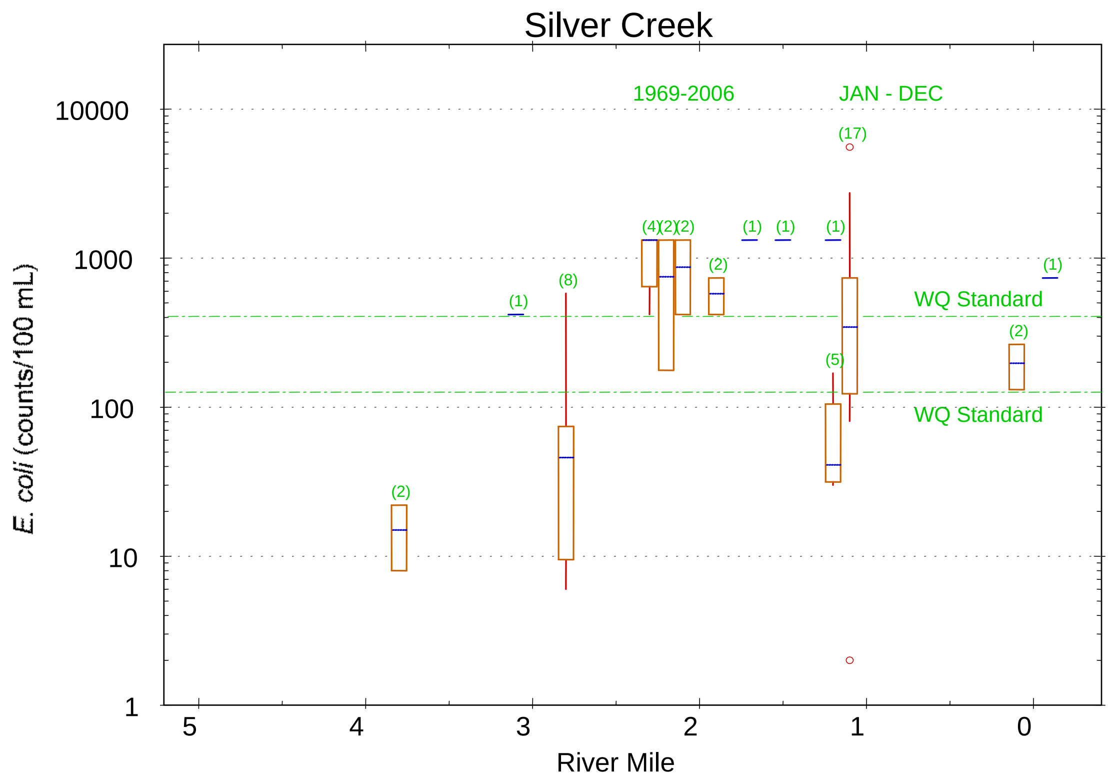

Figure G- 8: Longitudinal view of year-round bacteria concentration variation measured at several sites on Silver Creek.

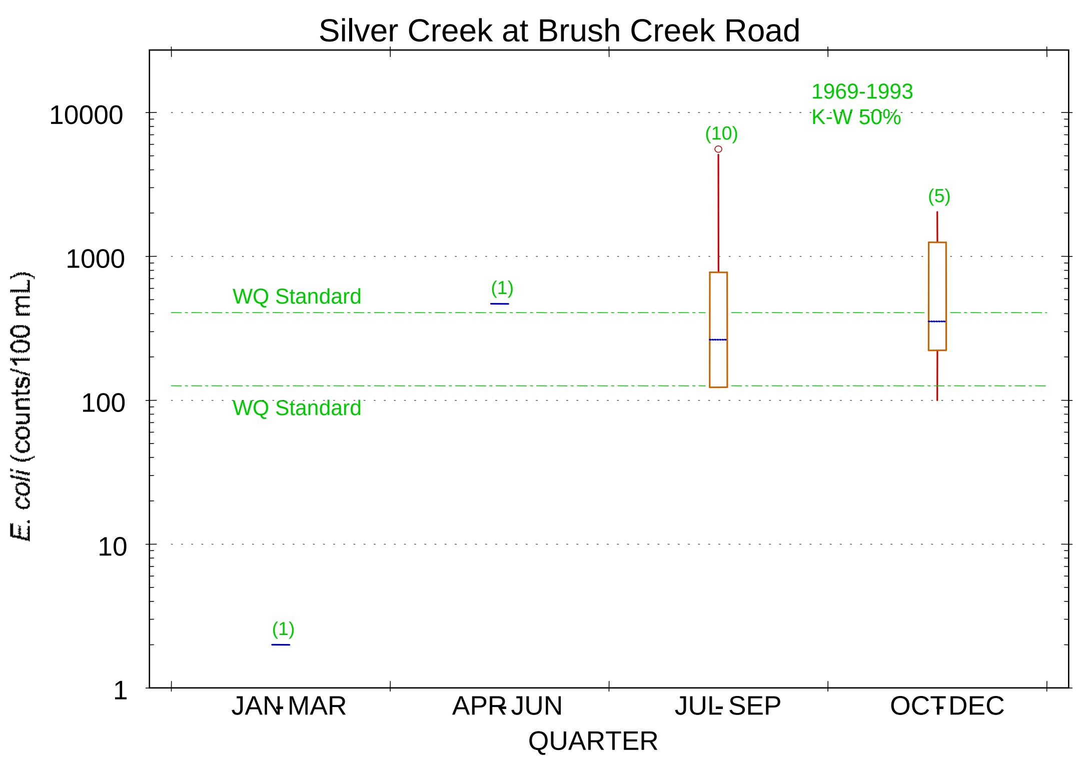

Figure G- 9: Quarterly distribution of Silver Creek bacteria data.

MOLALLA

With the exception of Milk Creek, few tributaries add significant flow to the lower Molalla River. Bacteria sources on the mainstem Molalla River are as likely to contribute to exceedances of the bacteria criteria as sources on the tributaries.

A review of longitudinal data for the Molalla River (Figure G- 10 through Figure G- 12) indicates little difference among the sites in the lower watershed with sufficient data for comparison. Bacteria data are not available from Molalla River tributaries, with the exception of a December 2004 sample collected in Milk Creek yielding less than 50 counts/100 mL *E. coli*. In the data sets collected from the lower two sites (Knights Bridge, river mile 2.8 and at Canby, river mile 3.8), outliers are responsible for most of the bacteria criteria exceedances. During winter months, the 75th percentiles of the data collected from the Highway 213 and Highway 99E sites exceed the 126 criterion.

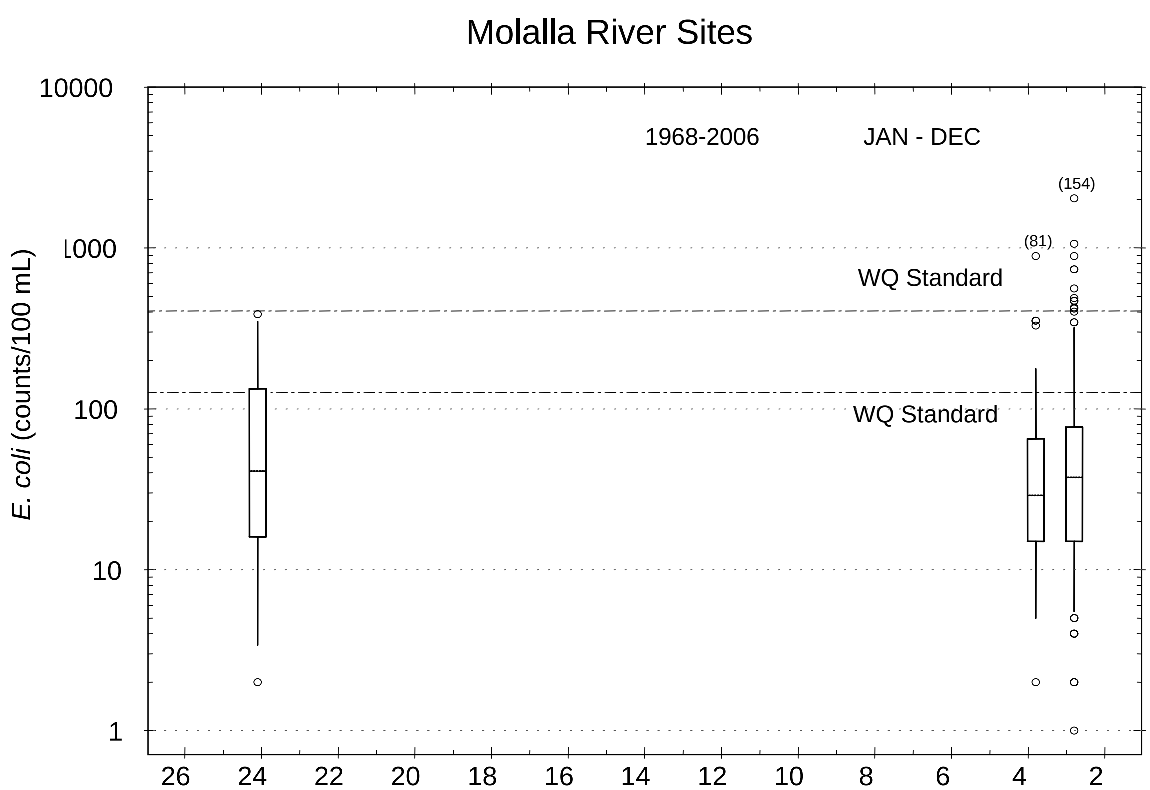

Figure G- 10: Distribution of bacterial concentrations measured year-round along the lower Molalla River. Fecal coliform data have been converted to equivalent E. coli counts. Horizontal lines indicate the two numeric E. coli bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

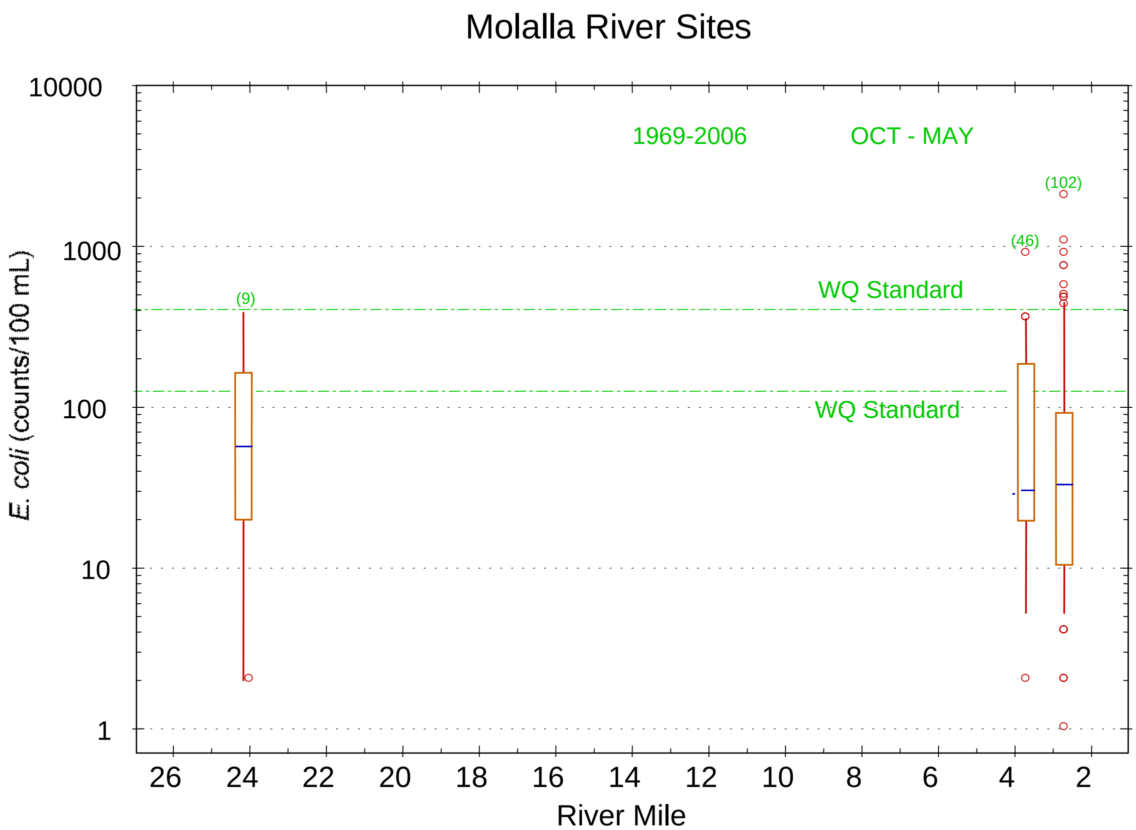

Figure G- 11: Distribution of bacterial concentrations measured in winter months (October – May) along the lower Molalla River.
Fecal coliform data have been converted to equivalent *E. coli* counts. Horizontal lines indicate the two numeric *E. coli* bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

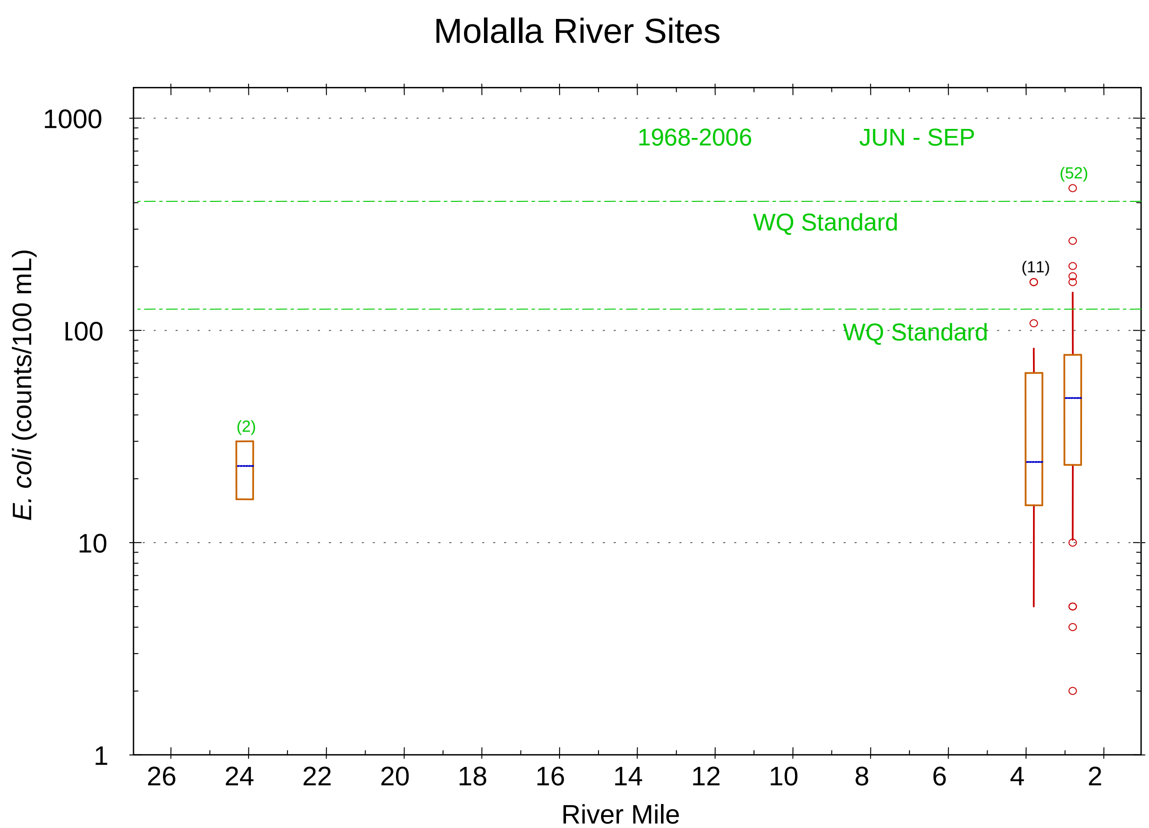

Figure G- 12: Distribution of bacterial concentrations measured in summer months (June - September) along the lower Molalla River.
Fecal coliform data have been converted to equivalent *E. coli* counts. Horizontal lines indicate the two numeric *E. coli* bacteria criteria, the 126 log mean criterion and the single sample 406 criterion.

The data from the Knights Bridge Road site, as analyzed by WQ Hydro (Figure G- 13), indicates a significant seasonality (99% confidence level), with the highest bacteria counts measured in the first quarter, January – March. Median concentration in no seasons exceed the 126 E. coli criterion, and the 75th percentile from only the first quarters' data exceeds the 126 criterion. Samples collected during an earlier time period from Molalla River at Canby, a mile upstream of the Knights Bridge site, indicate seasonality as well (99% confidence level, Figure G- 14), but the season with the highest median concentration is the fourth quarter (October – December).

The data set decreases significantly as one moves upstream to the next site, Molalla River at Highway 213. Limited conclusions can be drawn from such a small data set. As shown in Figure G- 15, based on the available data, the confidence level that at least one of the seasons differs from the others is 75%. The highest concentrations were measured in the first quarter, January – March. Median concentrations at this site are at or below the 126 criterion.

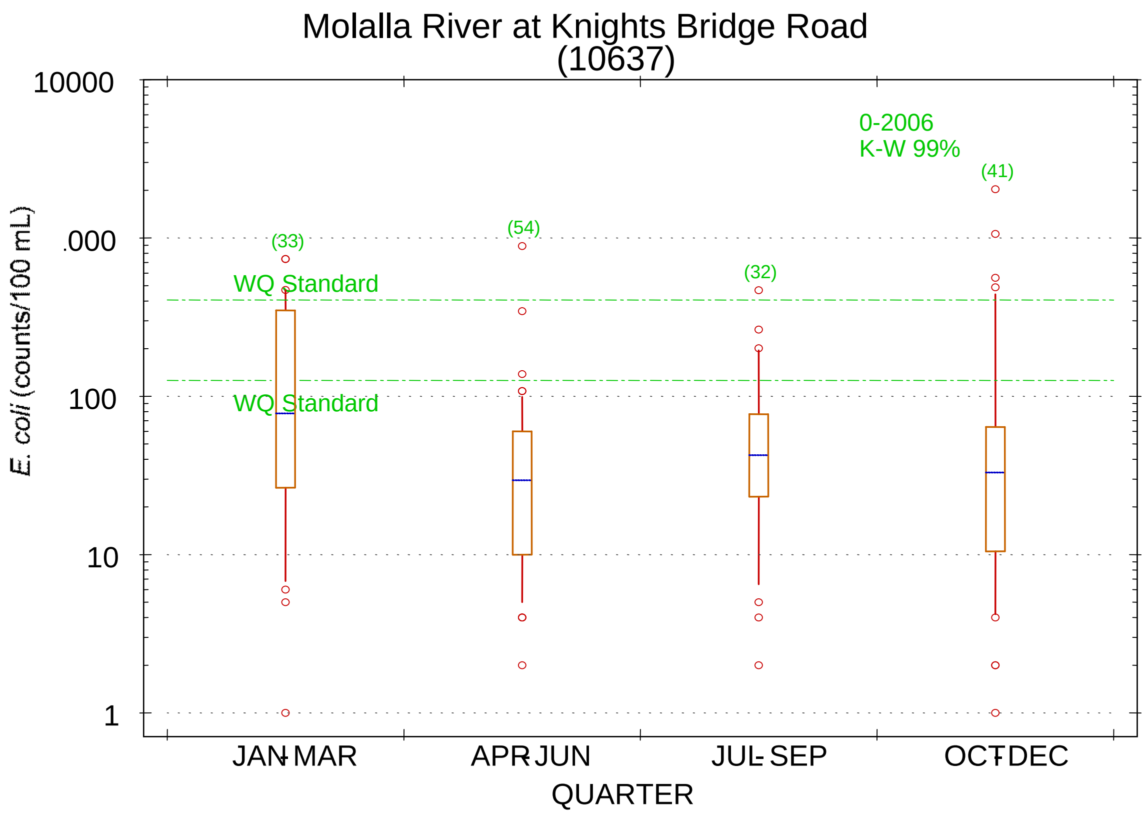

Figure G- 13: Seasonal distribution of bacteria data collected from Molalla River at Knights Bridge Road. Fecal coliform data have been converted to E. coli equivalents.

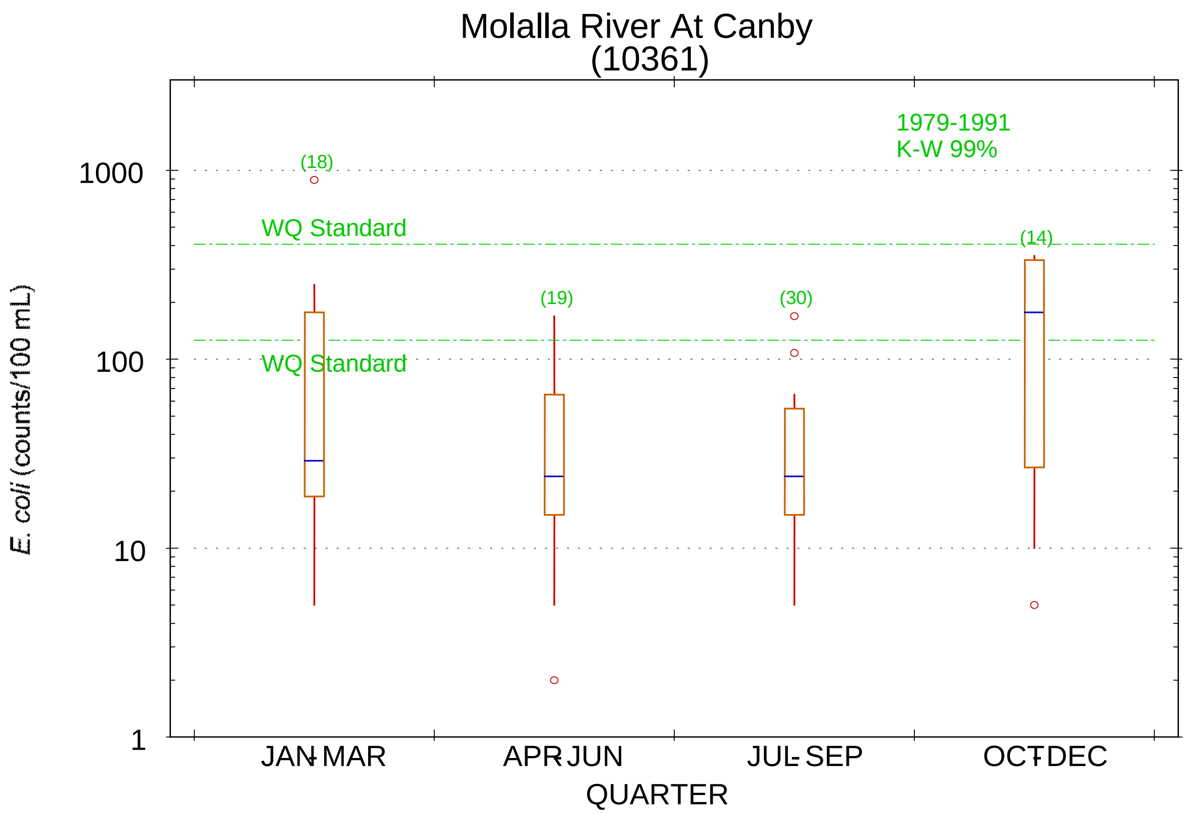

Figure G- 14: Seasonal distribution of bacteria data collected from Molalla River at Canby. Fecal coliform data have been converted to E. coli equivalents.

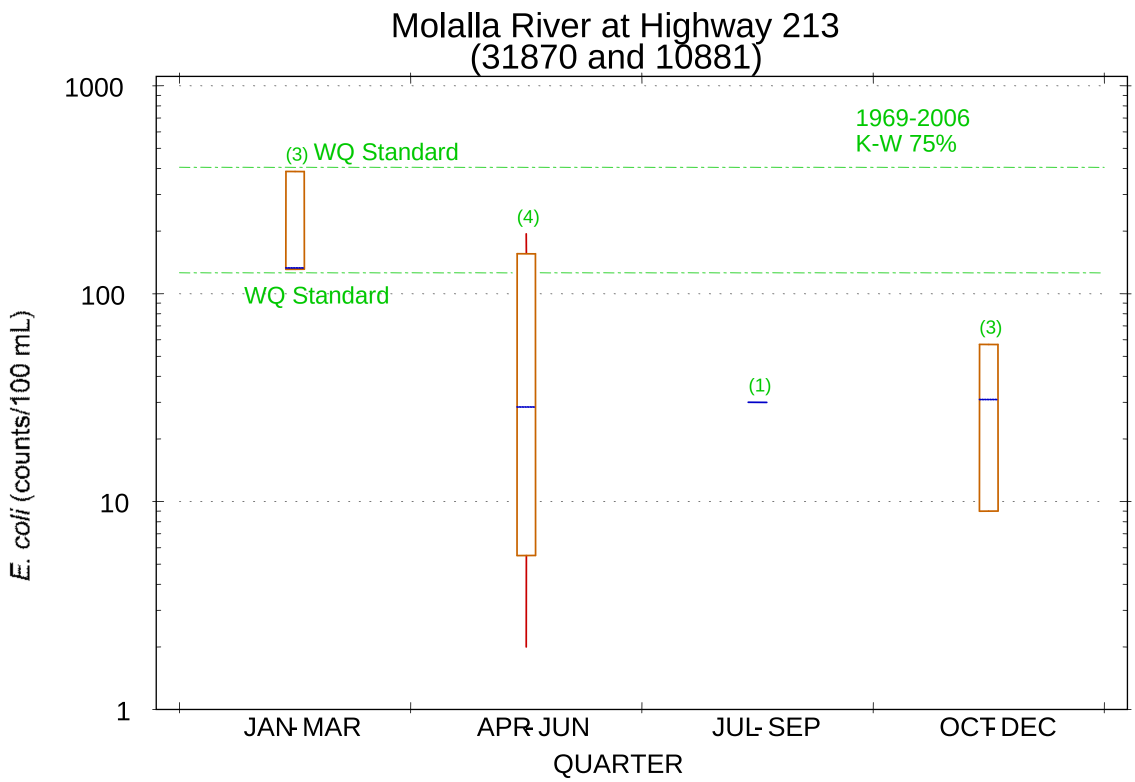

Figure G- 15: Seasonal distribution of bacteria data collected from Molalla River at Highway 213. Fecal coliform data have been converted to E. coli equivalents.

FLOW AND PRECIPITATION RELATIONSHIPS

DEQ developed load duration curves for sites with sufficient measured or estimated stream discharge data. These sites included the Pudding River at Highway 99E and Highway 211, Zollner Creek at Monitor-McKee Road, Silver Creek at Brush Creek Road, and Molalla River at Knights Bridge Road. As an approximation of background conditions, DEQ constructed load duration curves for three sites upstream of agricultural and urban development: Molalla River upstream of North Fork Molalla, Pudding River at Saratoga Road, and Butte Creek at Butte Creek Road. If sufficient stream discharge data were not available, DEQ developed a concentration duration curve. In a concentration duration curve, the exceedance probability against which bacteria concentrations are plotted is an average exceedance probability for the whole Molalla-Pudding subbasin. The average exceedance probability is calculated from stream flows available in the subbasin during that period. A hypothetical example is presented here:

> Example Average Exceedance Probability Calculation
>
> A hypothetical sample is collected from a stream on July 20, 1997. The stream from which the sample is collected is ungaged or the gage was not active on that day, so a load cannot be calculated. If some streams in the subbasin were gaged at that time, an average subbasin-wide exceedance probability can be calculated. For example, six streams in the subbasin had active gauges and therefore average daily stream flow data measured on July 20, 1997. The historical record for each of those six gages is consulted and the exceedance probability for each of the gaged streams on July 20, 1997 is recorded. If the exceedance probabilities for the 6 available gauges for July 20, 1997 were: 14%, 23%, 17%, 14%, 12%, and 19%, the average exceedance probability for July 20, 1997 would be 16.5%. The sample

concentration from the ungaged stream, collected on July 20, 1997, would be graphed against an exceedance probability of 16.5%, a low flow scenario.

In this discussion, a bacteria criteria “exceedance” is defined as a point that plots above one or both of the criteria curves, one based on 126 counts/100 ml and the other on 406 counts/100 mL. A criteria violation occurs only when the log mean of five samples (collected in a 30-day period) exceeds the 126 counts/mL criteria or when a single sample exceeds the 406 counts/100 mL criteria. Violations are not evaluated in this discussion because there are rarely five samples collected in a 30-day period at any given site.

In the load duration curves presented in the following figures, loads associated with dry conditions (less than 0.15 inches of precipitation in the previous 24 hours) are denoted with circular symbols and those associated with wet conditions (0.15 inches or greater precipitation in the previous 24 hour period) are denoted with square symbols. Precipitation data is recorded at the Aurora airport and DEQ obtained this data through the Oregon Climate Service. Winter (denoted with a dot) and summer (denoted with an “x”) are defined as October 1 – May 31 and June 1 – September 30, respectively.

The load duration curve representing conditions at the Pudding River at 99E (Figure G- 16) indicates that a larger percentage of bacteria criteria exceedances occur at high flows, typically corresponding with winter months (October 1 – May 31). Approximately 40% of the exceedances are associated with at least 0.15 inches of precipitation in the preceding 24 hours (square markers in Figure G- 16).

The load duration curve representing conditions approximately 13 miles upstream, at Highway 211 (river mile 21, Figure 23), indicates that exceedances occur across a range of flow conditions. Approximately 35% of exceedances occur in the summer months and most (77%) of the exceedances occur under dry conditions (less than 0.15 inches of precipitation in the last 24 hours – circle markers in Figure G- 17). Few 406 criterion exceedances occur in the summer months.

Recall that the seasonal signature (i.e. the difference between the quarterly median concentrations) was stronger at the lower Pudding River site (Highway 99E at river mile 7.3) than the Highway 211 site (river mile 21). This difference in the distribution of exceedances in the load duration curves also indicates a tendency toward higher concentrations during the winter at the Highway 99E site (river mile 7.3) and exceedances more evenly distributed throughout the year at the Highway 211 site (river mile 21).

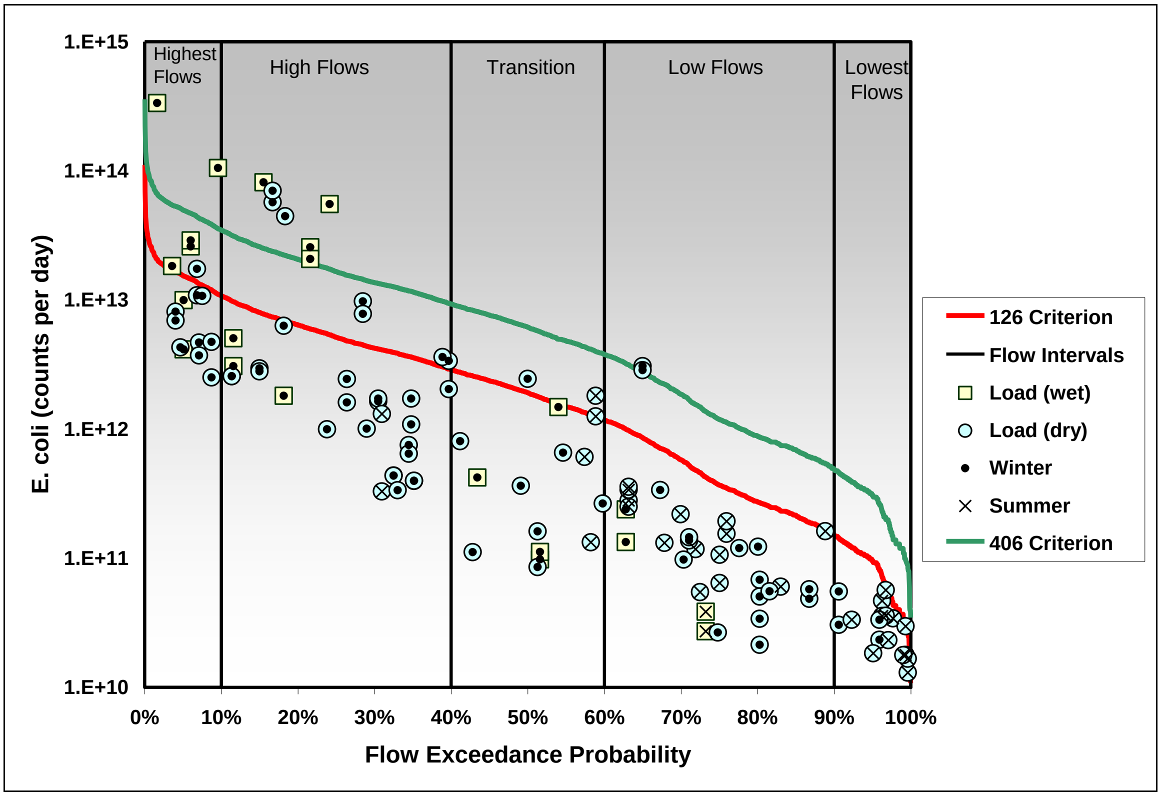

Figure G- 16: Load duration curve for Pudding River at Highway 99E, RM 7.3, from 1973 – 2006 data. USGS gage Pudding River at Aurora.

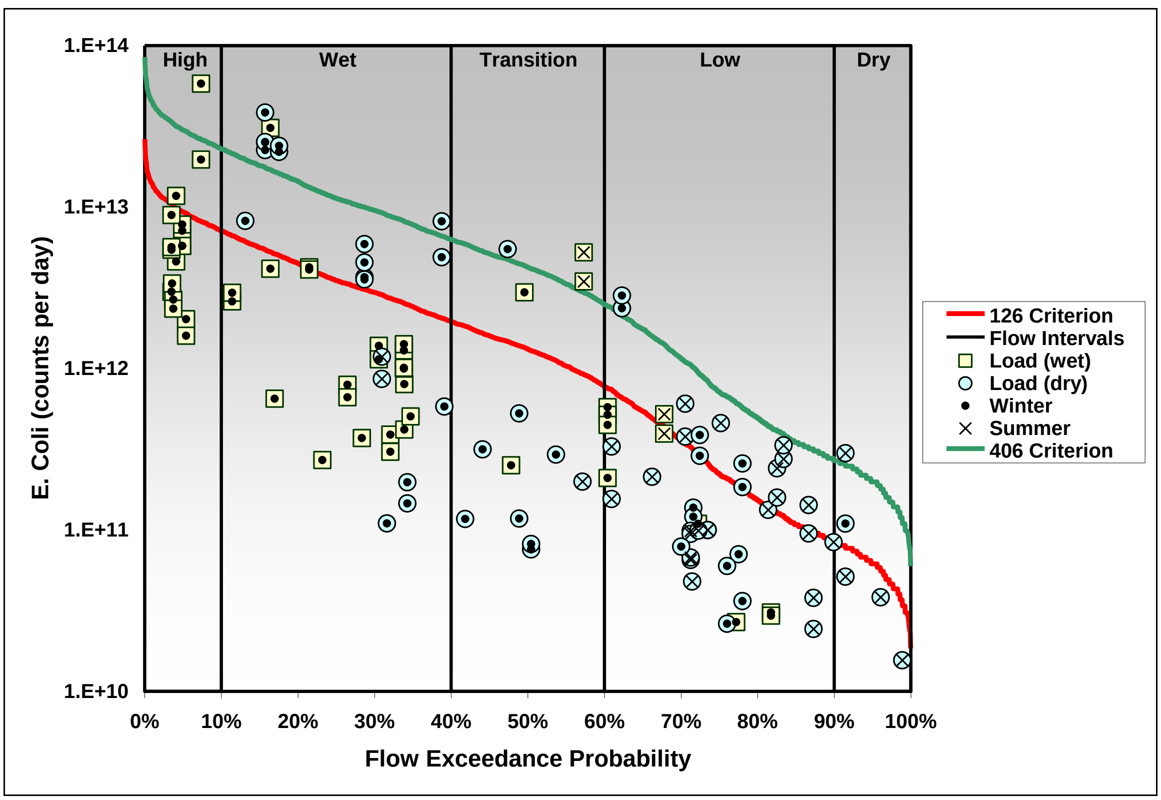

Figure G- 17: Load duration curve for Pudding River at Highway 211, RM 21, from 1969 – 2006 data. USGS Gage Pudding River near Woodburn.

To evaluate whether a bacteria source between the two sites might be responsible for the different seasonal patterns, DEQ compared the two sites with a Wilcoxon-Mann-Whitney Rank Sum analysis (Appendix H, Figure H-1). This analysis requires that the data sets be thinned to only those dates when a sample was collected at each of the two sites (n = 98 for each site). The analysis indicates no significant difference in the means of the two data sets or the concentrations measured at each of the two sites on any given day are not likely to differ significantly (2xP = 0.869). The difference in exceedance patterns at the two sites, then, may reflect different flow or physical characteristics between the sites (e.g. stream discharge, channel shape, stream bank stability) rather than different bacteria source areas.

The load duration curve combining data from two sites further upstream in the Pudding River watershed (river miles 41 and 44) (Figure G- 18) indicates that bacteria concentrations tend to follow the loading capacity curves, occasionally exceeding them, but not indicating severe or strongly seasonal bacteria loading. Low flow exceedances tend to occur during dry summer periods, and high flow exceedances during wet winter period. DEQ did not collect samples from the Pudding River at Saratoga Road site (river mile 41) under low flow conditions, so expanded the data set with four data points from samples collected at Nusom Road, three miles upstream. No major tributaries enter the Pudding River between these two sites, so the stream flow measured or estimated at Saratoga Road is a reasonable estimation of the flow at Nusom Road. Stream flow was measured at Saratoga Road from 1939 until March 31, 1966. To estimate stream flow at the time the Saratoga and Nusom Road samples were collected (1989 – 2006), DEQ relied on the strong correlation of historical stream flows measured at Saratoga Road with historical stream flows measured at each of three other basin gauges. DEQ used one of the three regression equations to estimate flow at Saratoga Road for the periods in which bacteria samples were collected. This limited data set indicates that exceedances of the log mean criterion (126 counts/100 mL) occur at both low and high flows, but concentrations do not exceed the 406 counts/100 mL criterion.

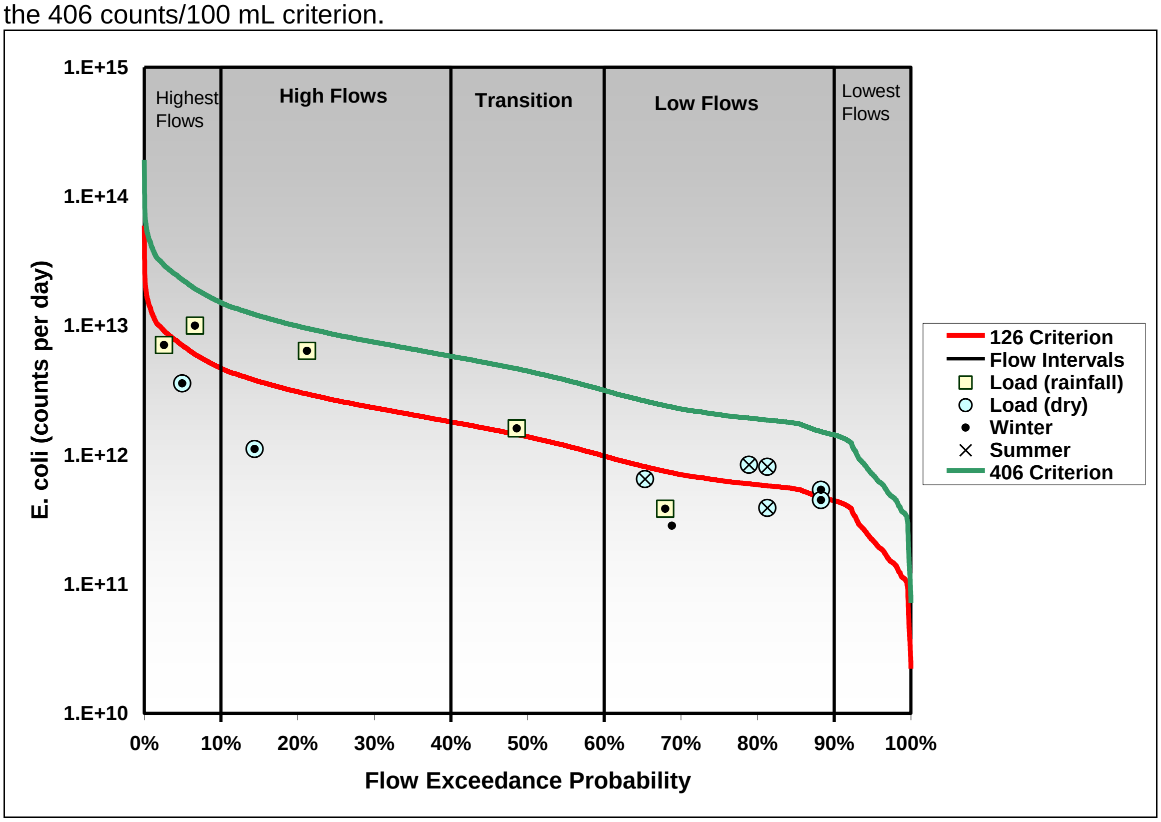

Figure G- 18: Load duration curve with data points combined from Pudding River at Saratoga Road (river mile 41) and Pudding River at Nusom Road (river mile 44).
Data period 1989 - 2006. Flow estimated from three USGS gages: Pudding River at Aurora, Molalla River at Canby, and Molalla River near Wilhoit.

Few sampling events from Zollner Creek took place during times that stream flow was also measured, and those few events occurred mainly during high flow conditions (Figure G- 19). The available data indicates exceedances during high flow periods, but exceedances at low flow periods are unknown because of a lack of data collected during those conditions. Since DEQ was not able to identify a stream with measured flow that correlated sufficiently with Zollner Creek flow, DEQ constructed a concentration duration curve with additional Zollner Creek bacteria data (Figure G- 20). Construction of a concentration duration curve is explained at the beginning of this section. Interpreting data from the concentration duration curve assumes that flows in Zollner Creek corresponded with flows in the gaged streams from which the estimated exceedance probability is calculated. Since flow is not known at the time and place of sample collection, loads are not shown in Figure G- 20, but rather concentrations are graphed with an average flow exceedance probability. The concentration duration curve reveals exceedances of the log mean and single sample bacteria criteria during both low flow and high flow periods. Exceedances are approximately evenly split between summer/winter months and wet/dry conditions. The summer/dry conditions, however, persist for a shorter period of time, so the frequency of exceedances in dry periods would be greater than those occurring during wet periods.

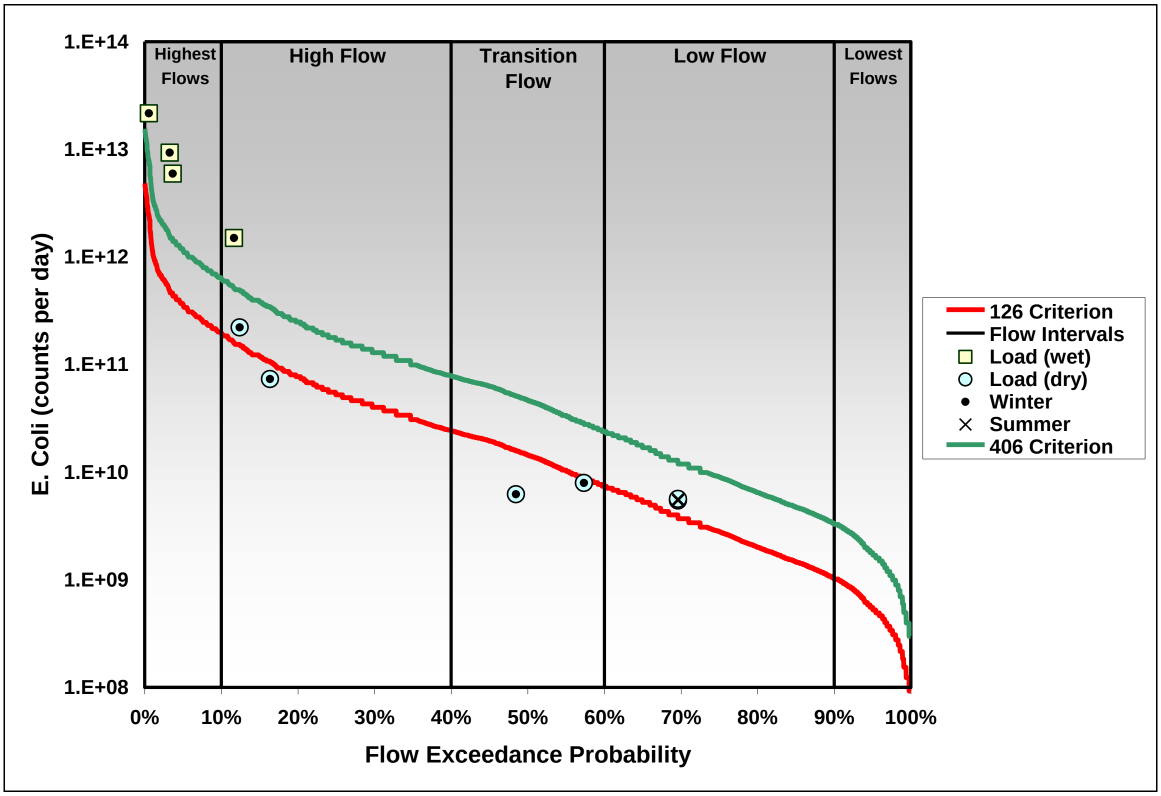

Figure G- 19: Load duration curve for Zollner Creek at Monitor McKee Road from 2004 – 2006 data. USGS gage Zollner Creek near Mt. Angel.

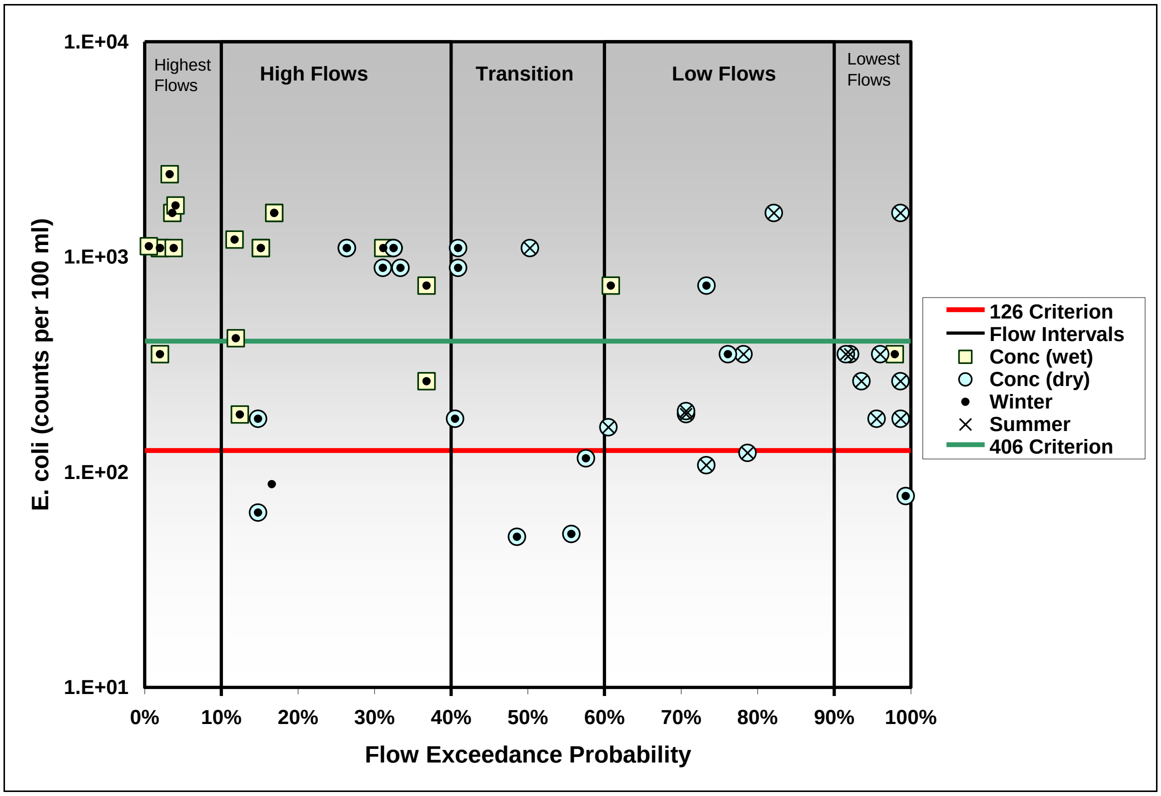

Figure G- 20: Concentration duration curve for Zollner Creek at Monitor McKee Road, from 1989 – 2006 data.

The load duration curve for Silver Creek at Brush Creek Road (river mile 1.3) was constructed using flow measurements collected or estimated at Silverton, approximately two miles upstream. This may be an underestimate of stream flow because the Silverton WWTP discharges at approximately river mile 2.9 (dry weather design flow is 3.5 million gallons/day), although the exceedance probability would be similar between the two sites. Figure G- 21 indicates greater frequency of log mean criteria exceedances during summer months and dry periods, but the data is likely biased because more data collection occurred in dry summer months. Most of the data collected during high flow periods also indicates exceedances of the 406 counts/100 mL criterion.

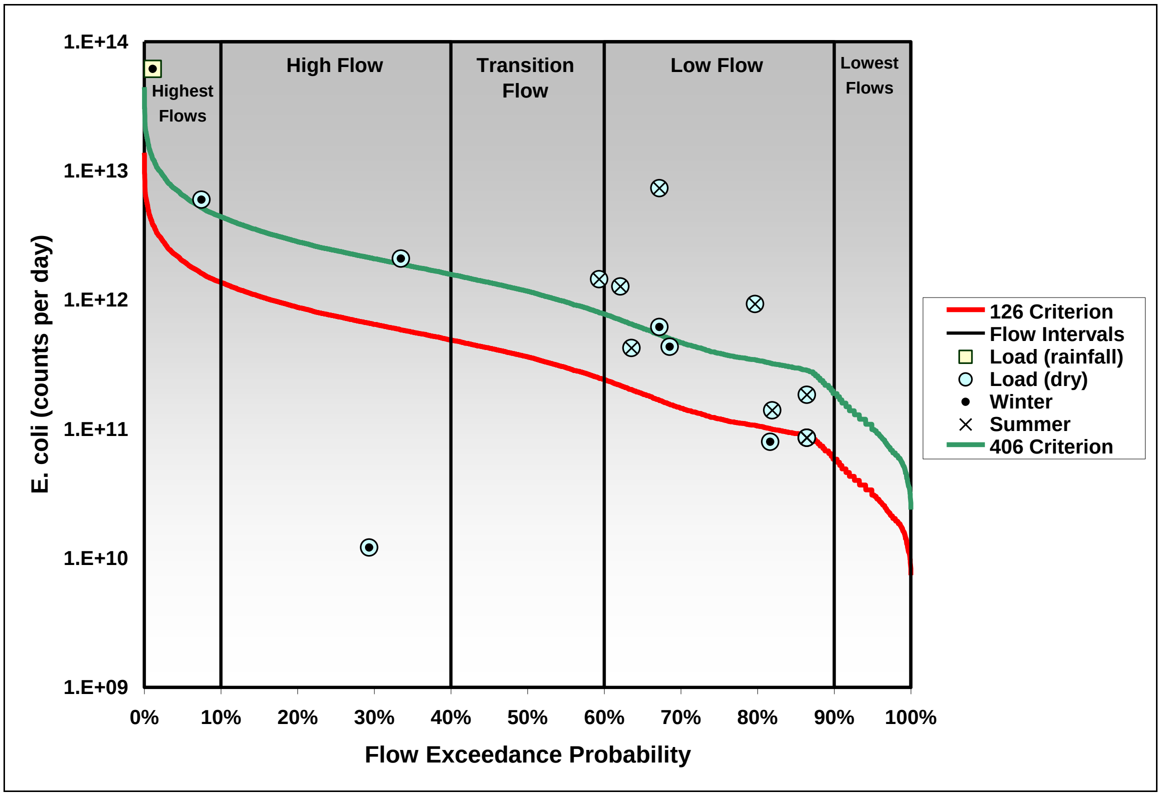

Figure G- 21: Load duration curve for Silver Creek at Brush Creek Road, data from 1969 - 1993. USGS Gage Silver Creek at Silverton.

Comparing the Zollner Creek and Silver Creek load and concentration duration curves with conditions from a site that is upstream of most agricultural and urban land uses (but not forestry land use), suggests that bacteria exceedances in these creeks derive from land use other than forestry, such as agricultural and urban. DEQ constructed a concentration duration curve for data collected from Butte Creek at Butte Creek Road (Figure G- 22) as a representation of conditions from predominantly forestry land use, since the site is upstream of agricultural and urban activities. Butte Creek is located in the drainage adjacent to the north of the Zollner Creek drainage, and enters the Pudding River at approximately river mile 18.5. Most sample results from this site at high and transition flows are near or below the log mean 126 counts/100 mL criteria. DEQ did not collect samples during a low flow period, so cannot make a conclusion about expected bacteria concentrations from predominantly forestry land use during dry, low flow periods.

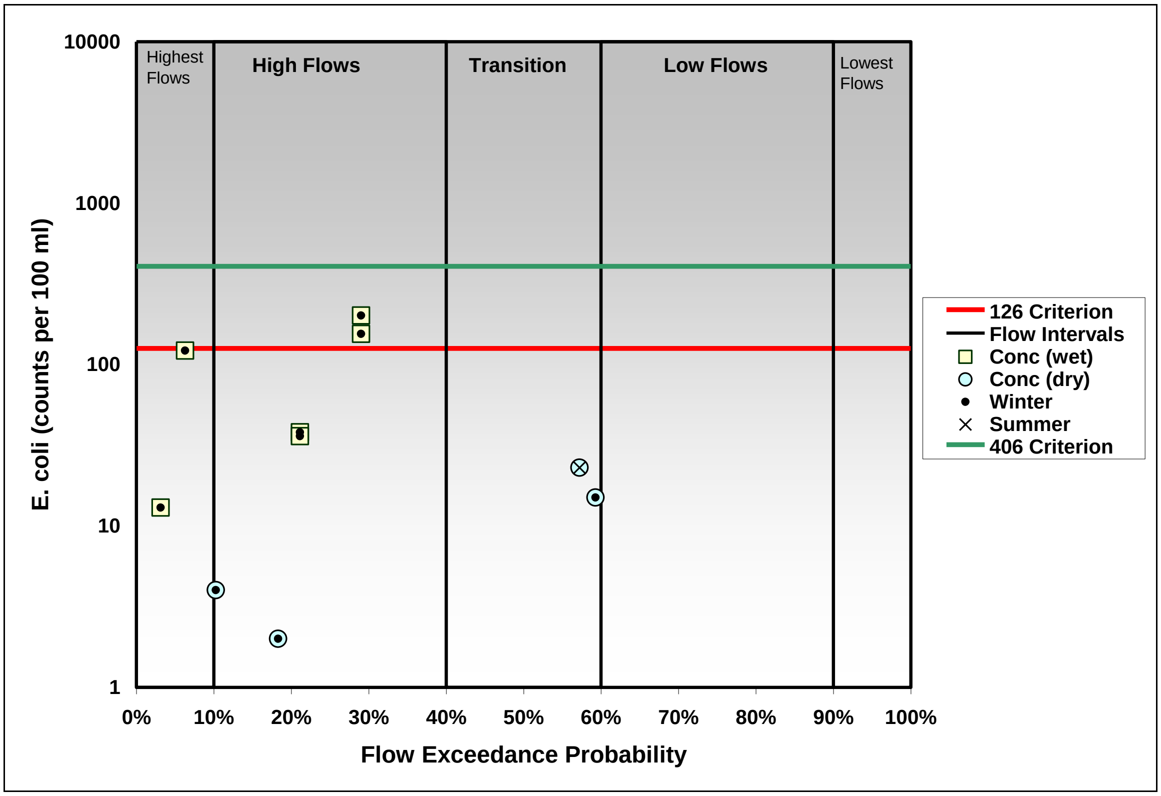

Figure G- 22: Concentration duration curve from Butte Creek at Butte Creek Road, representative of mainly forestry land use.
Data period 2005 – 2006.

Bacteria data collected from Molalla River at Knights Bridge Road (river mile 2.8, Figure G- 23) indicate that most of the criteria exceedances at this location have occurred under transitional to high flow conditions. Though the data set from Molalla River upstream of North Fork Molalla River (river mile 25, Figure G- 24) is quite small, the data suggest that background conditions do not contribute bacteria concentrations above the criteria, even under high flow conditions.

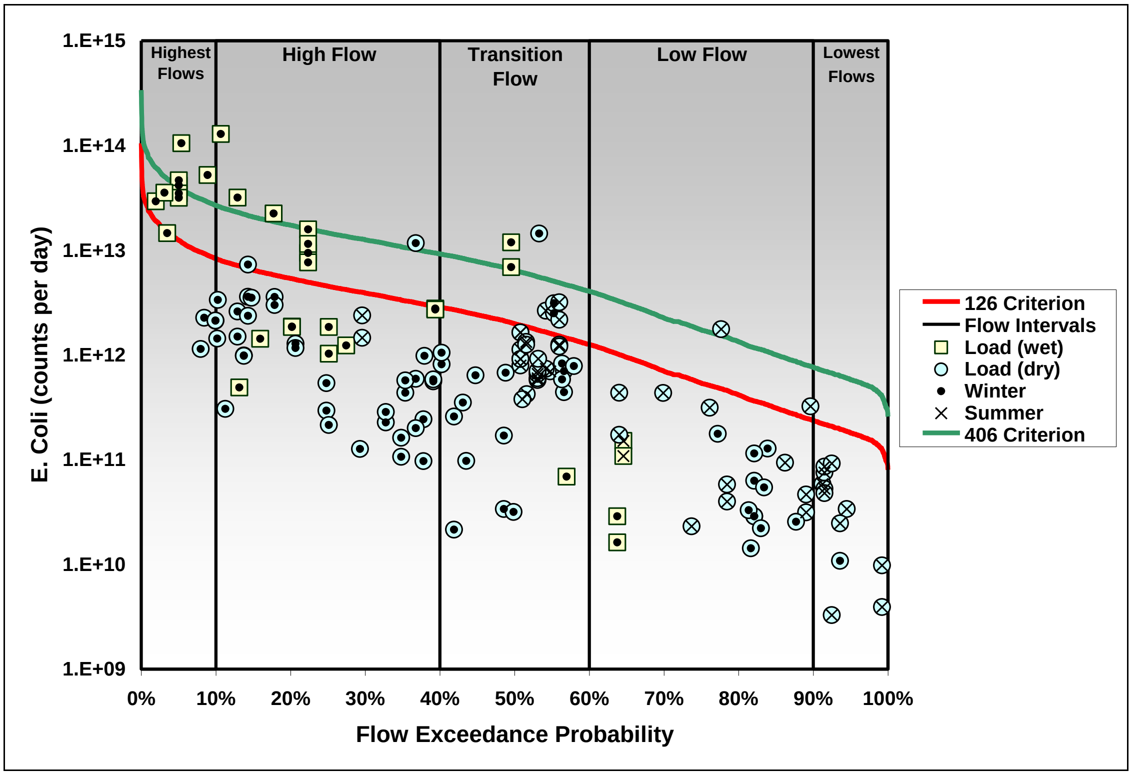

Figure G- 23: Load duration curve for Molalla River at Knights Bridge Road, from 1968 – 2006 data. USGS Gage Molalla River near Canby.

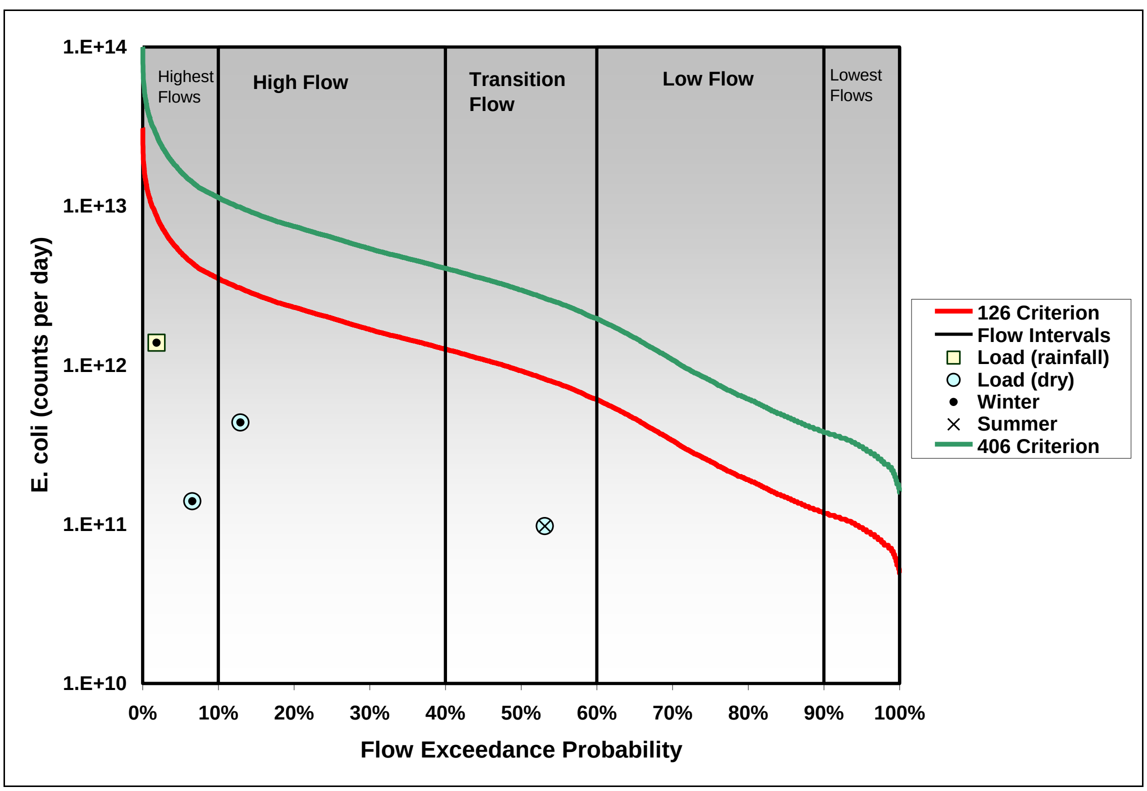

Figure G- 24: Load duration curve for Molalla River upstream of North Fork Molalla, river mile 25. Data period 2004 – 2006. USGS gage Molalla Rive near Wilhoit and estimated from Molalla River near Canby.

Summary

The Pudding River's response to bacteria loading differs with distance downstream. While bacteria concentrations measured at two sites, Highway 211 (river mile 21) and 99E (river mile 7.3), are similar, loads calculated at the upstream site exceed the log mean and discrete sample load duration curves across all flow regimes, while exceedances at the lower site correlate more with high stream flow and likely runoff events. Measurements collected at the most upstream two sites on the Pudding River (river miles 41 and 44), show that during high and low flows, individual sample bacteria concentrations can exceed the 126 counts/100 mL criterion, but tend not to exceed the 406 counts/100 mL single sample criterion.

Data collected from Silver Creek shows log mean and discrete sample bacteria criteria exceedances at both high and low flows, and probable source areas include both urban and agricultural land use. Zollner Creek also experiences significant exceedances of both log mean and discrete sample criteria throughout the year. The particularly high concentrations in Zollner creek may result from a small watershed and little opportunity for dilution. The source of bacteria loading to Zollner Creek is from agricultural land use, as there is no significant amount of urban land in the Zollner Creek watershed. Winter violations likely result from runoff while summer violations may result from irrigation return flow.

The data collected from a Pudding River tributary site downstream of predominantly forestry land use (Butte Creek at Butte Creek Road) shows that though bacteria exceedances may occur at high flow events, they are much lower in magnitude than the exceedances observed in Zollner and Silver Creeks.

The bacteria criteria exceedances on the Molalla River are associated with high flow events during the winter months. A small data set collected from a site downstream of predominantly forestry land use does not indicate bacteria concentrations exceeding the 126 counts/100 mL log mean criterion, even during highest flow events.

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