WILLAMETTE BASIN

TOTAL MAXIMUM DAILY LOAD (TMDL)

APPENDIX A: BACTERIA

September 2026

Prepared by

State of Oregon
Department of Environmental Quality

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BACTERIA TECHNICAL APPENDIX

TABLE OF CONTENTS

BACTERIA LABORATORY ANALYSIS METHODS

The majority of data analyzed for development of the Willamette Bacteria TMDL was of *E. coli* concentrations. Fecal coliform data were also analyzed in some water bodies as identified in each Subbasin and mainstem Willamette TMDL. The methods of bacterial analysis have changed over time, with some ODEQ samples analyzed using the Most Probable Number (MPN) technique and some analyzed using the membrane filtration technique (MF). Regardless of the analytical technique, available bacteria data have been combined.

For a number of years, ODEQ has used a 30 hour holding time standard from sample collection to analysis (see http://www.deq.state.or.us/lab/qa/techdocs.htm *E. coli methodology and holding time* for complete discussion). The agency is required to follow the methods listed in 40 CFR Part 136 or the agency may request approval for an alternate test procedure from USEPA. The listed methods do not specifically recommend holding times, however, there are holding time quality control procedures found elsewhere in the referenced documents. In 1996, the agency used available documentation and verbal communications with USEPA to make the scientifically valid and pragmatic decision to start bacterial testing within 30 hours of sampling. A literature review indicates bacteria density will drop as the environmental sample is held prior to its analysis. This evidence suggests that ODEQ's bacteria results will have a discernible negative bias due to the 30 hr. holding time. This does not preclude the data from being useful, rather it makes it a more conservative estimate of the bacteria population. Therefore it is acceptable to use this data for triggering remediation activities, should the data indicate violations of water quality bacteria standards.

Quality Assurance

ODEQ employs quality assurance checks on the data it uses for the TMDL analysis and grades the data quality A+ through C based on duplicate sample results and method reporting requirements. Bacteria sample results are graded with an A+ or A if duplicate samples have a difference less than 0.5 on a log scale. For results graded with a B, duplicate samples have a difference greater than 0.5 on a log scale. Certain bacteria analysis methods require the reporting of an estimated value depending on sample dilution. If data is reported as an estimate it receives a 'B' grade. Results graded C has no duplicate samples taken. ODEQ uses only results graded with A+, A, or B for TMDL analysis. Sample results reported below the detection limit were used in analyses as 0.8 of the detection limit and rounded to the nearest whole number. Sample results reported greater than the upper detection limit (2,419 org./100 ml.) were used in the analyses as the detection limit.

The measurement of bacteria concentrations can vary considerably. Analysis of 227 duplicate fecal coliform samples collected in Oregon during 1996 and 1997 reveals a root mean square error of 0.37 log. Bacteria concentrations typically are log-normally distributed. A log normal distribution implies that the variability of a population increases with greater values. When considering the median shellfish standard of 14 fecal coliforms / 100 milliliter (ml), the concentrations between 6 and 33 fecal coliform /100 ml would fall within intrinsic measuring error. *E. coli* concentrations exhibited a similar pattern with a root mean square error of 0.30 log. Concentrations between 203 and 810 *E. coli* / 100 ml fall within intrinsic measuring error of 406 *E. coli* / 100 ml. The water quality standards for fecal bacteria account for this variability by looking at a number of samples, for example the median and 90th percentiles of a sample.

LOAD DURATION CURVES

Load duration curves are a method of determining a flow-based loading capacity, assessing current conditions, and calculating the necessary load reduction. The methodology is based on TMDLs completed by the Kansas Department of Health and Environment. The two necessities for a load duration curve are flow data and water quality data at the same location.

Flow Data

The first step is creating a flow duration curve. The flow duration curve is a plot of the frequency of which a flow is exceeded. The flows are ranked from maximum to minimum for the period of record, in the example in Table 1. the period of record is January 1, 1990 until January 13, 2003. The exceedence probability (*EP*) for each flow is then computed by the following equation, where *n* is the number of flow measurements:

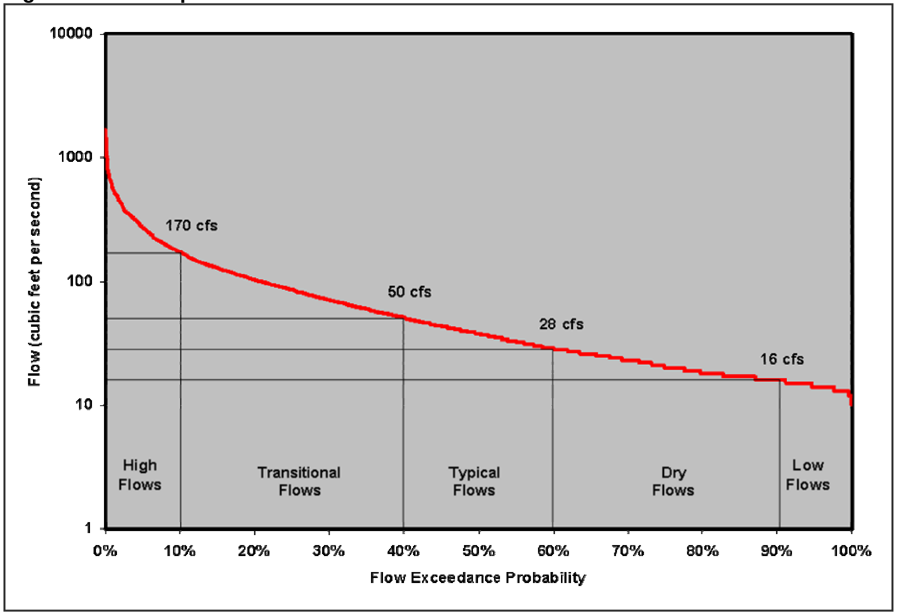
$$EP = \frac{rank}{n+1}$$

Table 1. Example of flow duration calculations

Flow (cfs)	Rank	% of Days Flow Exceeded
15,200	1	0.00006
15,200	2	0.00012
14,800	3	0.00018
…	…	…
0.1	16,739	0.99994

The "flow exceedance probability" is the exceedance probability multiplied by 100. The data are plotted with the flow exceedance probability on the x-axis and the flow in cubic feet per second on the y-axis (log scale), Figure 1. The flow duration curve is divided into five flow categories: high (0% to 10%), transitional (10% to 40%), typical (40% to 60%), dry (60% to 90%), and low (90% to 100%). Separating the flow data into five categories allows for an expanded characterization of the flow and pollutant data by identifying a pattern analysis, storm flows, and seasonal influence of the flow on the pollutant. A value of 5% on the x-axis indicates extremely high flows, while a value of 95% indicates drought conditions. For example, Figure 1 illustrates that 90% of the measured flows exceeded 16 cubic feet per second (cfs).

Figure 1. Example of flow duration curve.

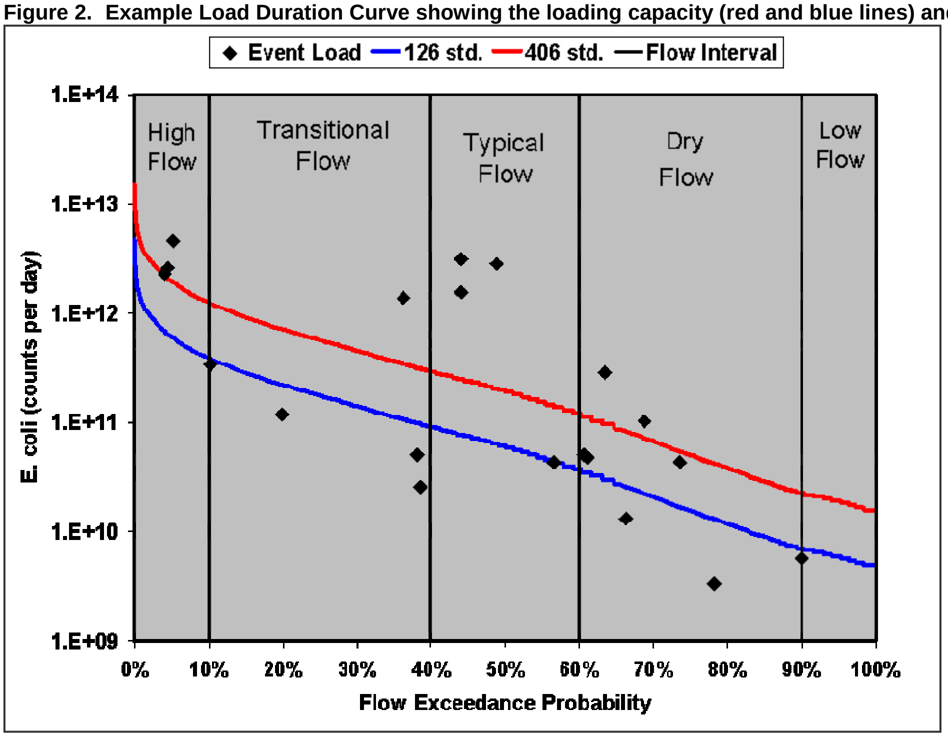


The flow duration curve generated for each sample site is then translated into a load duration curve. To accomplish this, the flow value is multiplied by the water quality criterion and a conversion factor, see equation below. The resulting loads are graphed and represent the flow-dependent loading capacity for specific numeric criteria. For example, the log mean recreational contact criterion for bacteria is 126 *E. coli* organisms per 100 milliliters so the loading capacity equation is:

$$Loading\ Capcity \frac{col}{day} = \overset{\substack{\text{Criterion}\\ \downarrow}}{126} \frac{col}{100\,ml} * \overset{\substack{\text{Flow}\\ \downarrow}}{Q} \frac{ft^3}{s} * \overbrace{283.2 \frac{100ml}{ft^3} * 86400 \frac{s}{day}}^{\text{Conversion factors}}$$

The loading capacity is then plotted against the corresponding flow exceedance probability, Figure 2. There are two lines representing the two numeric targets: log mean of 126 *E. coli* organisms / 100 ml (blue line) and no samples exceeding 406 *E. coli* organisms / 100 ml (red line). The loading capacity increases with increased flow because of the increased assimilative capacity of the river. A water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow recorded on the day the sample was taken. The "event loads" are plotted along with the criteria lines to assess current conditions. The y-axis becomes the water quality parameter value, load in this case. The position of the sample on the x-axis illustrates the flow exceedance probability (Figure 2).

Figure 2. Example Load Duration Curve showing the loading capacity (red and blue lines) and event loads (diamonds).



The load duration curve can then be used to estimate the percent reduction that is necessary to meet the applicable criterion in-stream. To determine what percent reduction is needed to achieve the loading capacity and thereby meet the 126 *E. coli* organisms/100 ml criterion, an estimate of the current load for each flow regime must be calculated. The current loading is determined by computing the log mean of the loads within each flow range. The flow based TMDL is the minimum load capacity within each range of flows (a conservative assumption). The percent reduction necessary to meet the TMDL is calculated by the following equation:

% reduction = (*current load* – *TMDL*) / *current load* * 100

Load duration curves allow land managers to identify generalized bacteria source contributions during different flow regimes. Table 2 can be used as a general guide for a flow-based source assessment.

Table 2. Generalized flow-based source assessment (Cleland, Sept. 2003)

	Range of Flows				
Possible Sources	High Flow	Transitional Flow	Typical Flow	Dry Flow	Low Flow
Point Sources	L	L	L	*M*	**H**
Failing On-Site Wastewater (Septic) Systems	L	L	**H**	*M*	L
Direct Delivery (i.e., swimmers, wildlife, pets, livestock in-stream, illegal dumping)	L	L	*M*	**H**	**H**
Riparian Areas	L	**H**	**H**	**H**	L
Combined Sewer Overflows (CSO)	**H**	**H**	**H**	L	L
Wastewater Treatment Plant Overflow	**H**	*M*	L	L	L
Stormwater: Upland	**H**	**H**	*M*	L	L
Stormwater: Impervious Areas	L	**H**	**H**	**H**	L
Re-Suspension	**H**	**H**	*M*	L	L
Overland Flow	**H**	**H**	*M*	L	L
Bank Erosian	**H**	*M*	L	L	L
Note: Potential relative importance of source area to contribute loads under given hydrologic condition (**H**: High; *M*: Medium; L: Low)					

With respect to wet-weather assessments, water quality impairments observed under the range of flow regimes typically reflect source loads associated with runoff events. Riparian areas and impervious surfaces can also contribute runoff related source loads under dry conditions. Development of meaningful source assessments that address impairments under these conditions should consider several concepts, which include runoff processes, runoff-contributing areas, and land use. Table 3 illustrates an approach that could be used to connect watershed process considerations with identification of potential runoff-contributing source areas using a load duration curve flow range (Cleland, Sept. 2003). Infiltration and saturation watershed processes both produce overland flow affecting runoff contributing to increased in-stream bacteria loads. Infiltration is the excess overland flow that occurs when precipitation intensity exceeds the rate of water infiltration into the soil (Juracek, 2000). This process may be dominant in watersheds where the land surface has been disturbed or where natural vegetation is sparse. Saturation is the excess overland flow that occurs when precipitation falls on temporarily or permanently saturated land surface areas (Hornberger, et al, 1998). A temporary water table can develop during a storm when antecedent soil-moisture conditions are high.

Table 3. Generalized Runoff Process Considerations.

	Range of Flows				
Contributing Source Area	High Flow	Transitional Flow	Typical Flow	Dry Flow	Low Flow
Woodland	S(H)	S(M)			
Grassland	S(H)	S(M)			
Cropland	S(H)	I(H)	I(M)		
Urban	S(H)	S(H)	I(H)	I(H)	
Riparian Areas	S(H)	S(H)	I(H)	I(H)	
S(H): Saturation-excess (High runoff potential) S(M): Saturation-excess (Medium runoff potential) I(H): Infiltration-excess (High runoff potential) I(M): Infiltration-excess (Medium runoff potential)					

Modified Load Duration Curves

Comparison of Historic Flow Data Sets

Due to funding cuts or equipment failure long term flow monitoring gages have not been fully operational for the period of record of interest. When no current stream flow gage data is available, an extrapolation of historic data is possible using flow data from a surrogate gage in an adjacent watershed or within the same watershed. The calculation of a flow duration curve is the bases for extrapolating flows for a discontinued gage. The flow duration curve is a plot of the frequency of which a flow is exceeded. The flows are ranked from maximum to minimum for the period of record at a particular site and then the exceedance probability (EP) for each flow is computed, similarly to a normal load duration curve.

The extrapolation process begins by identifying a operational flow gage with a similar drainage area, similar flow duration curve, and overlapping period of record as the expired flow gage. The operational flow gage becomes the surrogate for the expired flow gage. Once a surrogate flow gage has been identified the modified load duration curve can be developed. An Excel based Flow Analysis Tool spreadsheet is used to calculate a flow duration curve for each flow gage. This spreadsheet was developed by Bruce Cleland of USEPA and America's Clean Water Foundation (www.acwf.org).

The Flow Analysis Tool spreadsheet produces a summary table of stream flows in cubic feet per second (cfs) and millimeters (mm) at each corresponding exceedance probability for the entire period of record. The flows recorded at each flow gage in cubic feet per second are normalized by the drainage area and are converted to millimeters. Flows expressed as millimeters are calculated by the Flow Analysis Tool spreadsheet to allow for a comparison of flow between watersheds of different drainage area size. Flows expressed in cfs are converted to mm as shown in the equation below:

$$Flow(mm) = \left(\frac{Flow(feet^3 / \mathrm{sec}) \times 86{,}400(Sec / day) \times 28{,}316{,}850(\mathrm{mm}^3/\mathrm{foot}^3)}{Drainage\,(mm^2)} \right)$$

Drainage = the area drained by the watershed at the location of the gage

For example, in the Flow Analysis Tool spreadsheet summary table shown in Figure 3, the flow at the 5% exceedance probability is 395 cfs or 3.39 mm which means that 5% of the flows recorded at this gage are higher than 395 cfs or 3.39 mm and 95% of the flows are lower. The Flow Analysis Tool spreadsheet calculates exceedance probabilities for every daily flow recorded.

Once the flow duration summary is completed for each flow gage during the overlapping period of record, a flow ratio for each exceedance probability interval is calculated. This is done by dividing the flow values from the expired flow gage by the surrogate operational flow gage. This calculated flow ratio is then used to adjust each daily flow value recorded at the surrogate flow gage, to include both the overlapping and current flow periods. Because there are no flow ratios for every flow value of a given exceedance probability, the ratios calculated are multiplied by all the recorded flows at the surrogate operational flow gage within a range of similar exceedance probability. For example, the flow ratio for the 5% exceedance probability would be multiplied by the flows with a exceedance probability range of 2.5% to 7.5%, see the Adjusted Flow equation below:

$$AdjustedFlow(mm) = FlowRatio(5\%EP) \times DailyAverageFlow(2.5\%to7.5\%EP)$$

The calculated flow ratio for each exceedance probability interval then becomes the new flow duration curve for the expired flow gage for the period of record of the operational flow gage.

Figure 3. Example of Output from the Flow Analysis Tool Spreadsheet

FLOW DURATION SUMMARY				USGS 14192000 MILL CREEK AT SALEM, OREG.		
	Peak to Low			***Low to Peak***		
	cfs	**mm**		**cfs**	**mm**	
0.007%	1870	16.06	***Peak***	1	0.00	***Low***
0.01%	1535	13.18		1	0.01	***0.01th Percentile***
0.10%	1022	8.78		4	0.03	***0.1th Percentile***
1%	620	5.32		12	0.10	***1th Percentile***
5%	395	3.39		23	0.20	***5th Percentile***
10%	300	2.58		33	0.28	***10th Percentile***
15%	240	2.06		40	0.34	***15th Percentile***
20%	200	1.72		47	0.40	***20th Percentile***
25%	170	1.46		53	0.46	***25th Percentile***
30%	146	1.25		59	0.51	***30th Percentile***
35%	128	1.10		65	0.56	***35th Percentile***
40%	112	0.96		72	0.62	***40th Percentile***
45%	100	0.86		80	0.69	***45th Percentile***
50%	89	0.764		89	0.76	***50th Percentile***
55%	80	0.687		100	0.86	***55th Percentile***
60%	72	0.618		112	0.96	***60th Percentile***
65%	65.0	0.558		128	1.10	***65th Percentile***
70%	59.0	0.507		146	1.25	***70th Percentile***
75%	53.0	0.455		170	1.46	***75th Percentile***
80%	47.0	0.404		200	1.72	***80th Percentile***
85%	40.0	0.344		240	2.06	***85th Percentile***
90%	32.7	0.281		300	2.58	***90th Percentile***
95%	23.0	0.198		395	3.39	***95th Percentile***
99%	12.0	0.103		620	5.32	***99th Percentile***
100%	0.6	0.005	***Low***	1870	16.06	***Peak***
33.3%	135	1.16	***Average***			

Upper Willamette Subbasin: Coyote Creek

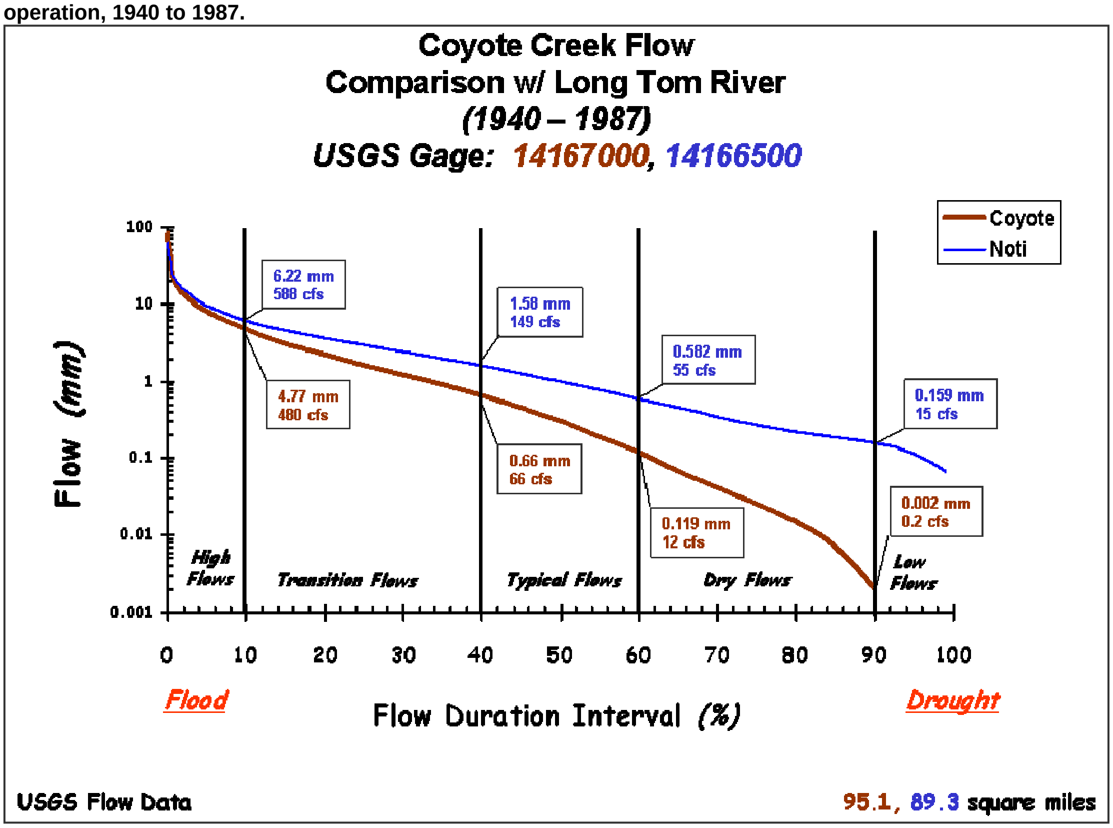
A modified load duration curve was developed for Coyote Creek in the Upper Willamette Subbasin (Chapter 10). This method was used to develop a flow duration curve for the discontinued flow gage in Coyote Creek near Crow Road based on the historic and real-time flows recorded in the Long Tom River near Noti.

The Coyote Creek flow gage was operational from July 1, 1940 to September 30, 1987. Information on the Coyote Creek USGS flow gage, # 14167000, can be accessed on the internet at: http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14167000
This flow gage is representative of a 95.1 square miles (60,864 acres) drainage area.

The Long Tom River USGS flow gage (# 14166500) has been operational since October 1, 1935. It is currently a real-time flow monitoring station. The flow data for the entire period of record is available on the internet at: http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14166500
This flow gage is representative of an 89.3 square mile (57,152 acres) drainage area.

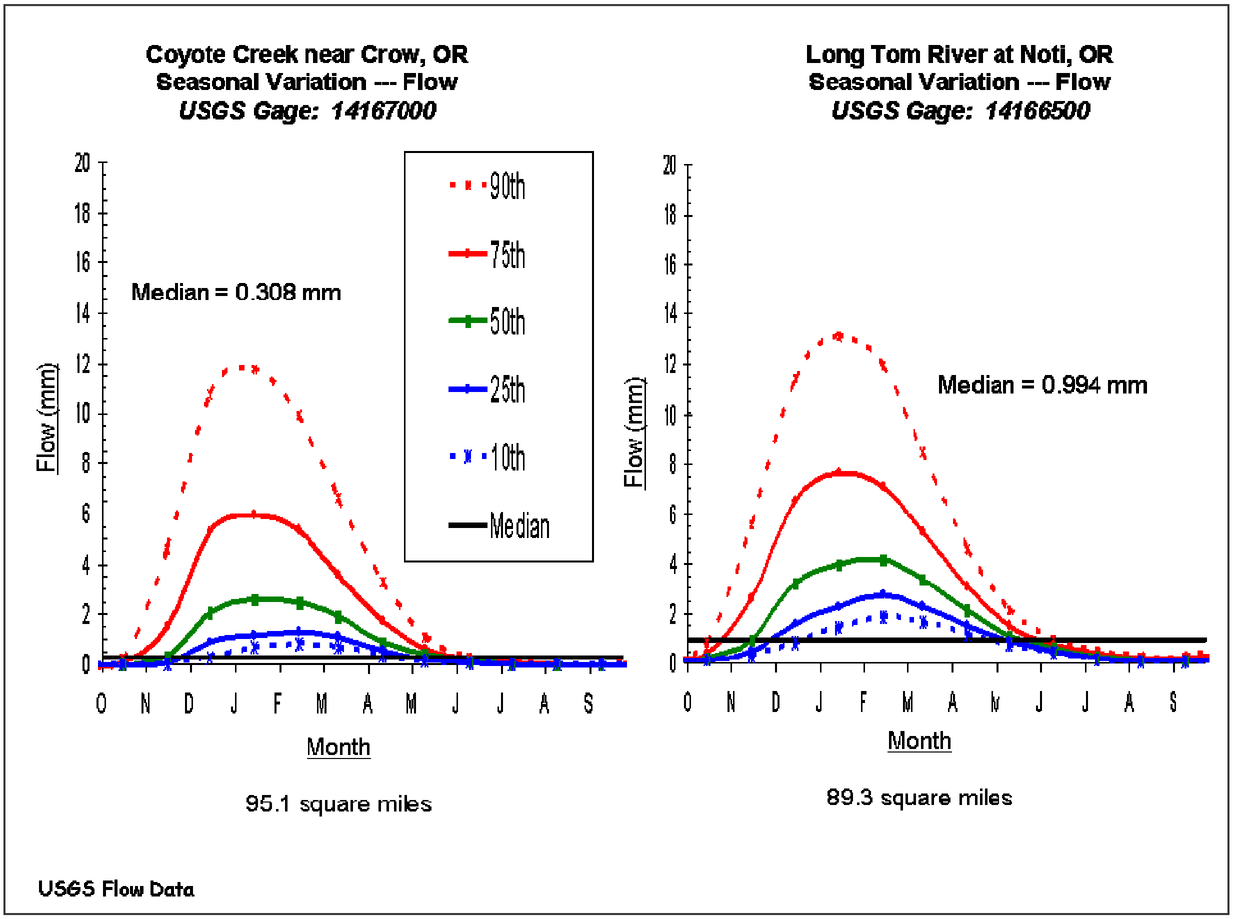
The modified flow duration curve was developed to create a load duration curve for the expired flow gage in Coyote Creek using the real-time flow gage in the Long Tom River to re-create a flow record for the expired flow gage. Both flow gages represent a similar drainage area, have an overlapping flow record, and are within the same watershed. The common, overlapping time flow period occurred during 1940 to 1987. The flow duration curve for the overlapping time period was plotted for each flow gage, Figure 4. The flow duration curved for Coyote Creek and Long Tom have similar flow regimes within the high flow duration interval and slowly diverge as flows decrease to the low flow interval.

Figure 4. Comparison of Flow Duration Curve for Coyote Creek and Long Tom River during the overlapping period of operation, 1940 to 1987.



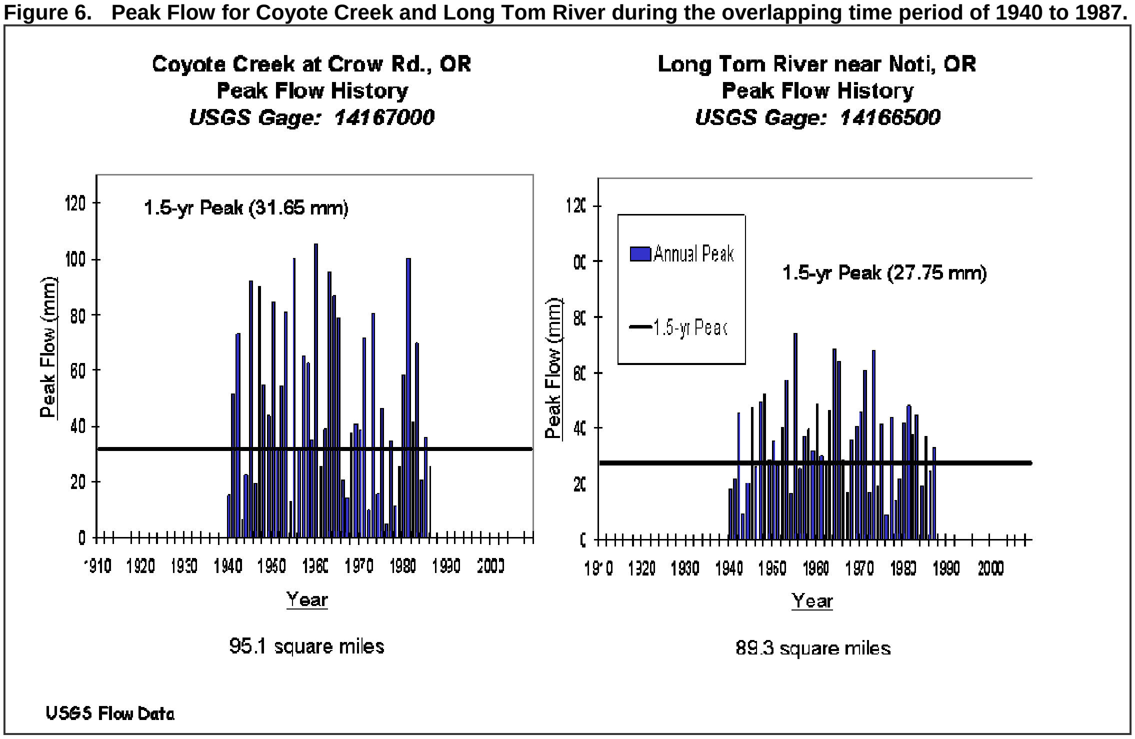
In addition to the flow duration curves, above, additional flow plots were developed to determine the variability and identify similarities between the two flow gages. The overlapping flow record, 1940 to 1987, was plotted to examine the seasonal variation between the two flow gages, Figure 5. Both flow gages begin to have increased high flows (90th percentile – red dotted line) starting in late December. Flows begin to decrease and fall below the median flow record in mid-June at both flow gages. The median flow in Coyote Creek, 0.308 mm, is less than one-third the median flow calculated for Long Tom River, 0.994 mm. The flows in Coyote Creek are lower in magnitude than the flows in the Long Tom River.

Figure 5. Seasonal Flow Variation for Coyote Creek and Long Tom River during the overlapping time period of 1940 to 1987.



Further comparison of the overlapping flow records for each flow gage examined the peak flow records, Figure 6. Peak flow history allows for identification of the magnitude and frequency of high flows. The calculated 1.5 year peak flow for Coyote Creek, 31.65 mm, is similar to the 1.5 year peal flow for the Long Tom River, 27.75 mm.

Figure 6. Peak Flow for Coyote Creek and Long Tom River during the overlapping time period of 1940 to 1987.



The Flow Analysis Tool spreadsheet was then used to develop a relationship between the two flow gages. The overlapping flow data, drainage area, and period of record dates were entered into the spreadsheet. The spreadsheets summary flow output tables were used to calculate a flow ratio for each exceedance probability interval. This is done by dividing the flow values from the expired flow gage, Coyote Creek, by the corresponding real-time surrogate flow gage, Long Tom River (Table 4).

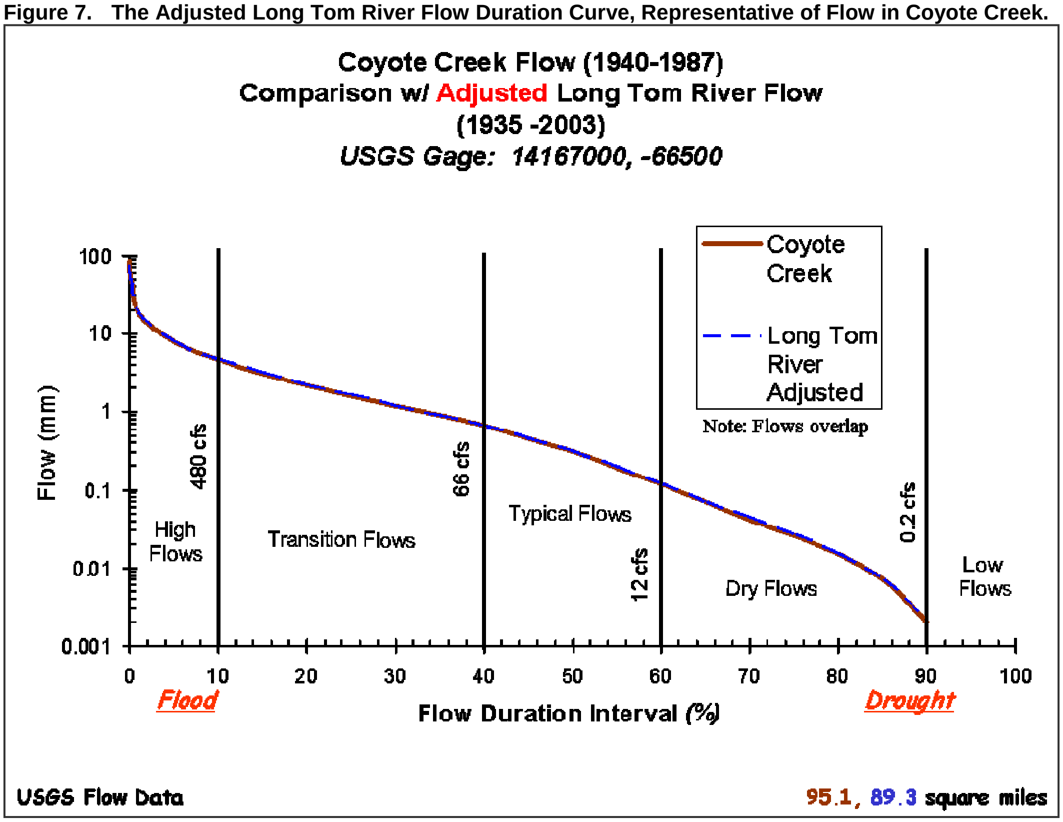
Table 4. Flow Ratio for Flow Values during Common Dates of Operation (1940 to 1987)

Exceedance Probability EP (%)	**Coyote Cr. At Crow Rd:** mm	**Long Tome River at Noti:** mm	**Adjustment Ratio** *(Coyote/Long Tom)*=
0.01%	72.04	59.17	1.218
0.10%	50.03	40.29	1.242
1%	18.59	19.78	0.94
5%	8.05	9.55	0.842
10%	4.77	6.22	0.767
15%	3.08	4.62	0.666
20%	2.19	3.62	0.603
25%	1.59	2.93	0.542
30%	1.19	2.41	0.494
35%	0.91	1.96	0.467
40%	0.66	1.58	0.416
45%	0.46	1.26	0.363
50%	0.31	0.99	0.31
55%	0.19	0.76	0.248
60%	0.12	0.58	0.205
65%	0.07	0.45	0.151
70%	0.04	0.35	0.117
75%	0.03	0.26	0.098
80%	0.01	0.22	0.067
85%	0.01	0.19	0.037
90%	0.002	0.16	0.013
95%	0	0.12	0
99%	0	0.07	0
100%	0	0	0

The calculated flow ratios are used to adjust each daily flow value recorded at the surrogate flow gage, Long Tom River. This ratio adjustment will calculate the stream flow representative of those that would have occurred at the Coyote Creek flow gage during both the period of overlapping operation and the entire period of record for Long Tom River.

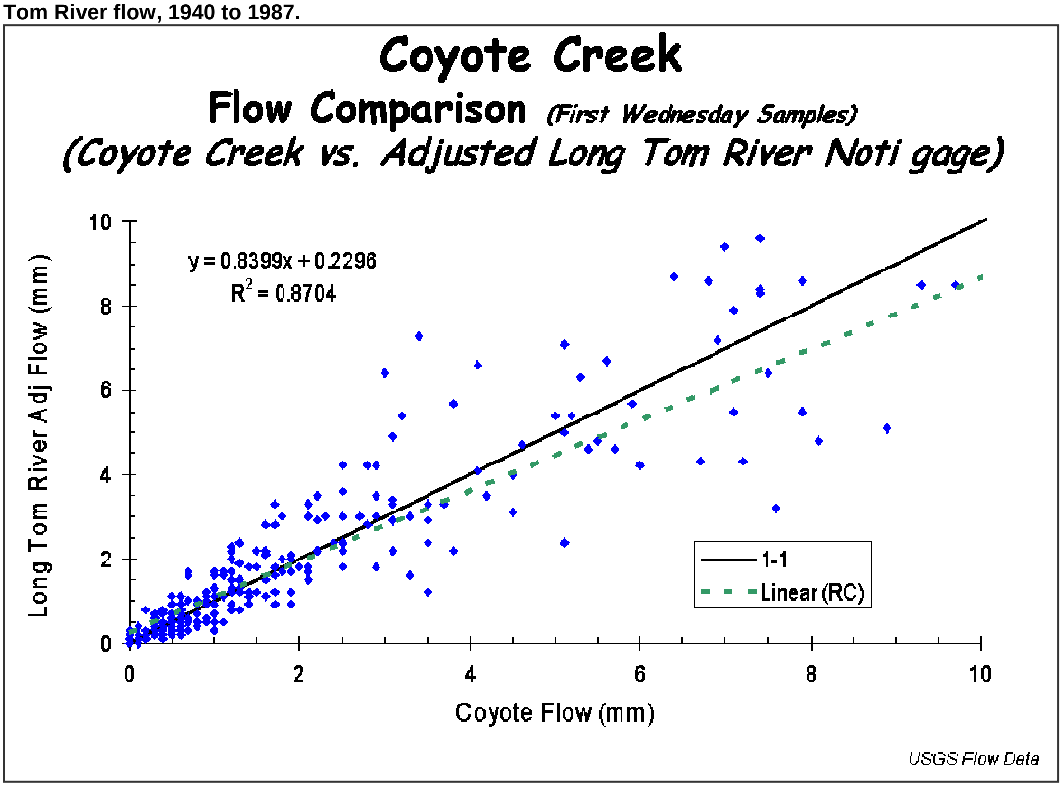
Once the flow values for the surrogate real-time flow gage, Long Tom River, have been adjusted by the calculated flow ratios (above), a new flow duration curve is calculated to derive a real-time flow regime for the expired flow gage, Coyote Creek. The new flow duration curve for Coyote Creek (expired flow gage) is overlapped onto the real-time flow gage at Salem in Figure 7. The adjusted flow duration curve for Long Tom River was used to develop the load duration curve for Coyote Creek, as used in the Upper Willamette Bacteria TMDL.

Figure 7. The Adjusted Long Tom River Flow Duration Curve, Representative of Flow in Coyote Creek.



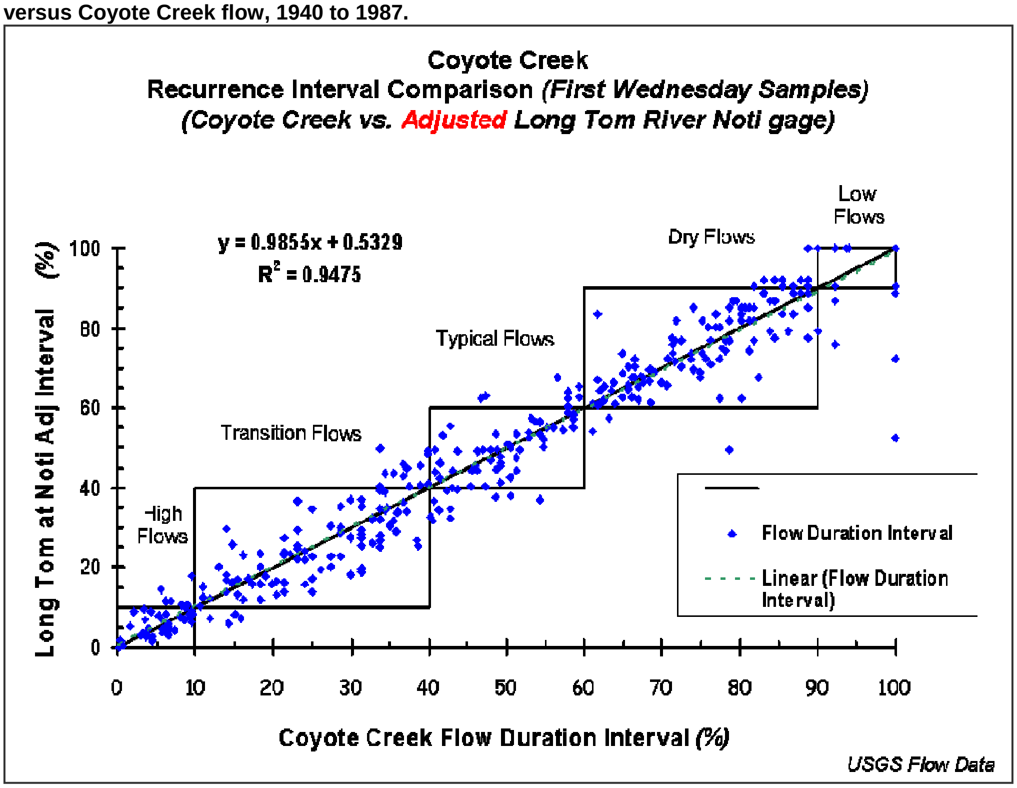
The output from the adjusted surrogate flow gage, Long Tom River, is compared to the output flow from the historic flow gage, Coyote Creek, to determine if the extrapolated flows are statistically similar to the historic flows. This analysis was done as a quality assurance measure to verify the statistical validity of the adjusted flows. The statistical validity of the adjusted flows have been verified by calculating the linear regression of the flow for each first Wednesday of the month for the overlapping period of record. The flow values from the adjusted flow gage in Long Tom River were plotted against the historic flow values recorded at the flow gage at Coyote Creek. The resulting flow comparison regression graph, Figure 8, has a calculated linear R-squared of 87%.

Figure 8. Flow Comparison of Historic First Wednesday of the Month Flows for Coyote Creek versus the adjusted Long Tom River flow, 1940 to 1987.



A flow recurrence interval for the first Wednesday subset flow data, above, was also developed, Figure 9. The flow recurrence interval plot, below, compares the timing of the flow recorded in Coyote Creek to the flow calculated by the adjusted Long Tom River flow gage. The regression plot has a calculated linear R-squared value of 94%. Data points plotted within each flow box represent a similar flow recurrence within each of the five established flow regimes (high, transitional, typical, dry, low).

Figure 9. Flow Recurrence Interval Comparison of Historic First Wednesday Flows for adjusted Long Tom River flow versus Coyote Creek flow, 1940 to 1987.



Middle Willamette Subbasin: Mill Creek

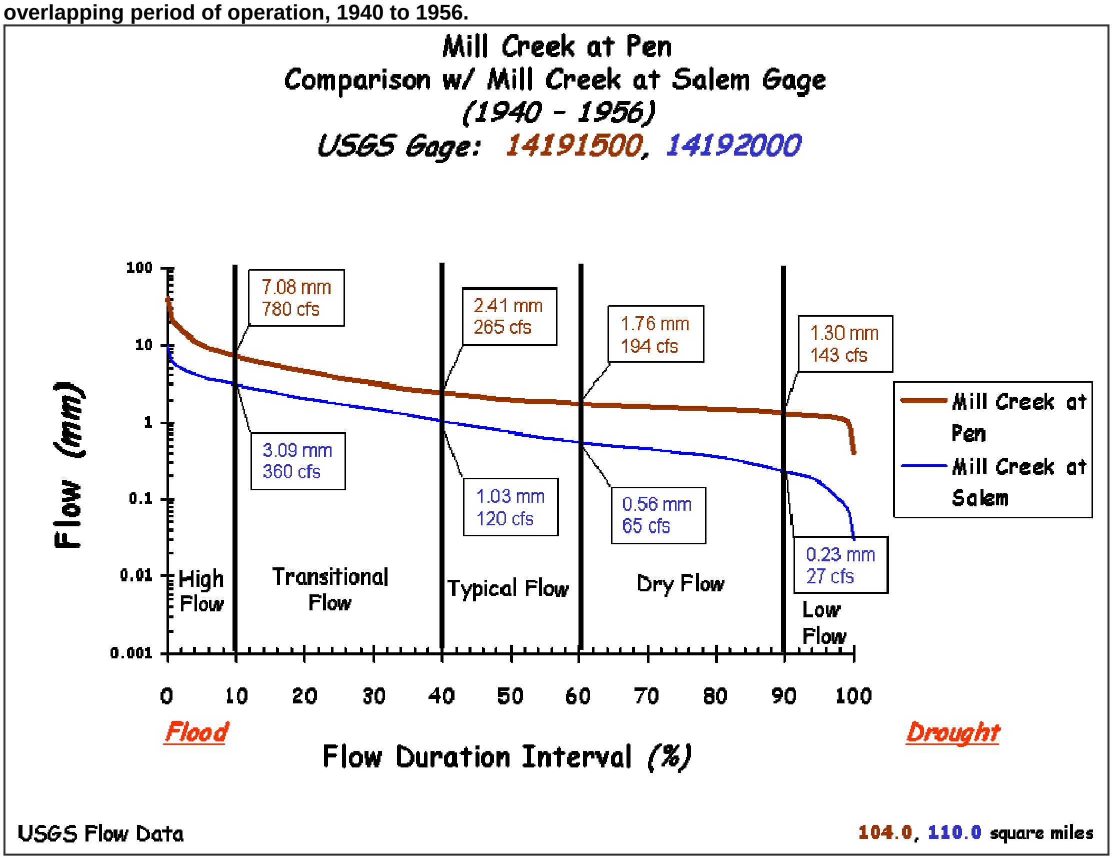
A modified load duration curve was developed for Mill Creek in the Middle Willamette Subbasin (Chapter 7). This method was used to develop a flow duration curve for a discontinued flow gage in Mill Creek at Penitentiary (Pen) annex near Salem based on the historic and real-time flows in Mill Creek at Salem. The historic Mill Creek at Pen flow gage is located within the Salem city limits at RM 7, upstream of both Shelton Ditch and Mill Race diversions. The real-time Mill Creek at Salem flow gage is located near the mouth of Mill Creek at RM 1.3, downstream of both Shelton Ditch and Mill Race diversions. Both flow gages are downstream of the seasonal diversion from the North Santiam River, upstream of the city of Turner.

The Mill Creek at Pen flow gage was operational from October 1, 1940 to September 30, 1956. Information on the Mill Creek at Pen USGS flow gage, # 14191500, can be accessed on the internet at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14191500
This flow gage is representative of a 104.0 square miles (66,560 acres) drainage area.

The Mill Creek at Salem USGS flow gage (# 14192000) was operational from October 1, 1940 to September 30, 1978. The historical flow data is available on the internet at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14192000
This flow gage became operational again in 1999 and is currently operational under OWRD supervision. Real-time flow data for this flow gage is available at:
http://odwr.e-monitoring.net/
This flow gage is representative of a 110.0 square mile (70,400 acres) drainage area.

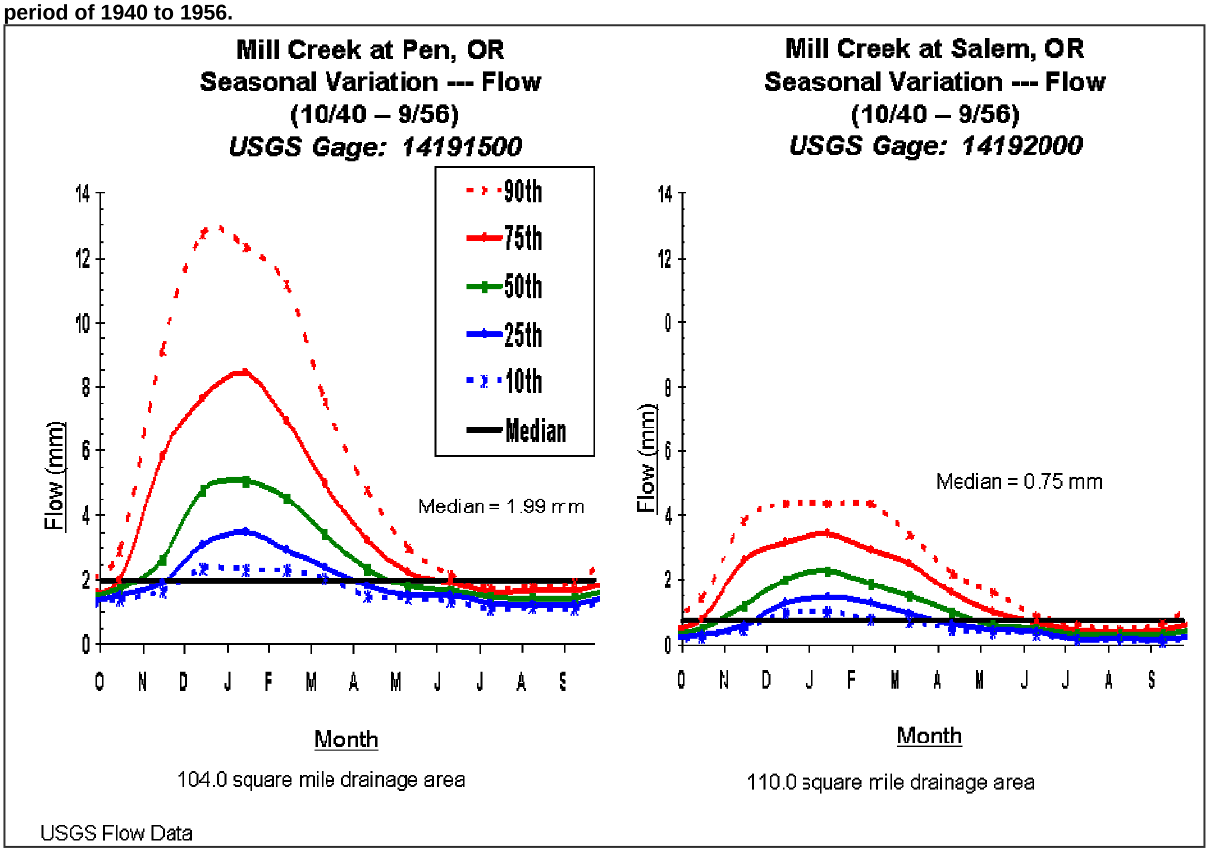
The modified flow duration curve was developed to create a load duration curve for the expired flow gage in Mill Creek at Pen using the real-time flow gage in Salem to re-create a flow record for the expired flow gage. Both flow gages represent a similar drainage area, have an overlapping flow record, are within the same watershed and water body, and are influenced by the diversion from the North Santiam River. The common, overlapping time flow period occurred during 1940 to 1956. The flow duration curve for the overlapping time period was plotted for each flow gage, Figure 10. The flow duration curve plot identifies a similar slope between the two flow gages during the overlapping time period (1940 – 1956).

Figure 10. Comparison of Flow Duration Curve for Mill Creek at Salem and Mill Creek at Pen during the overlapping period of operation, 1940 to 1956.



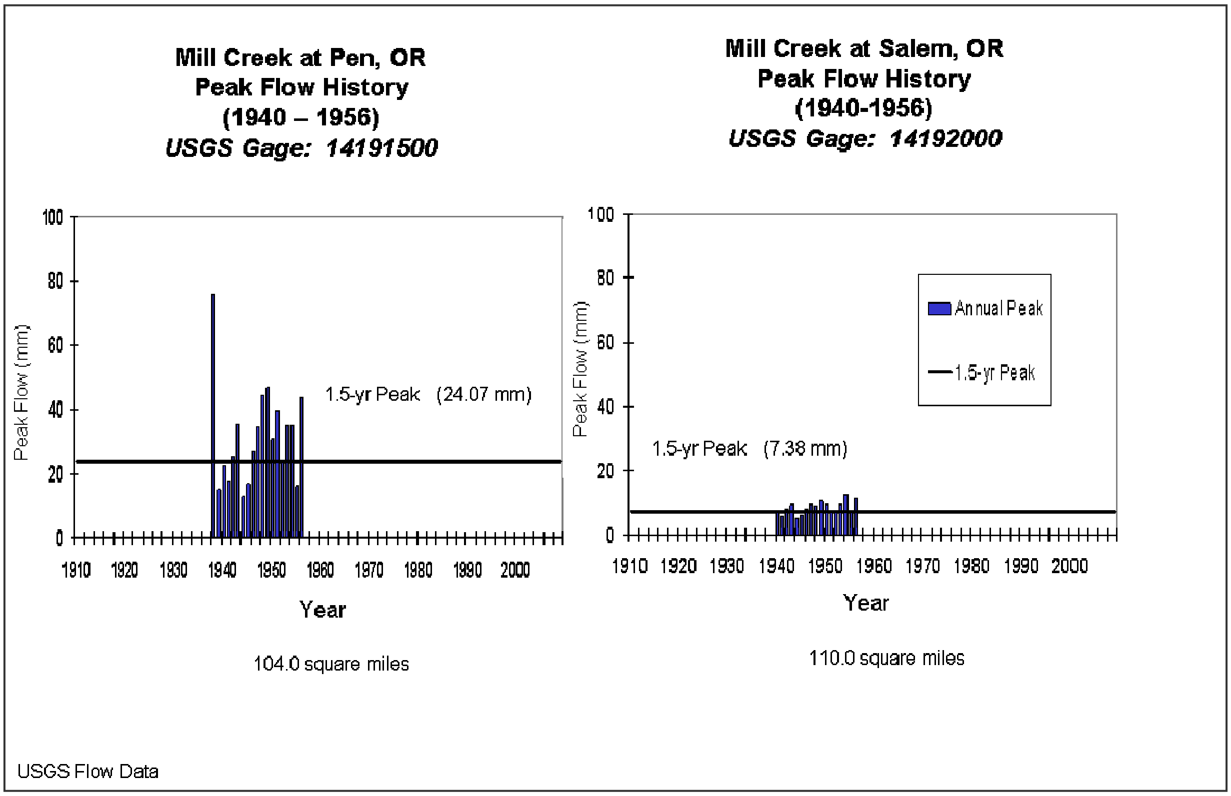
In addition to the flow duration curves, above, additional flow plots were developed to determine the variability and identify similarities between the two flow gages on Mill Creek. The overlapping flow record, 1940 to 1956, was plotted to examine the seasonal variation between the two flow gages, Figure 11. Both flow gages begin to have increased high flows (90th percentile – red dotted line) starting in late October. Flows begin to decrease and fall below the median flow record in mid-June at both flow gages. The median flow in Mill Creek at Pen, 1.99 mm, is more than twice the median flow calculated for Mill Creek at Salem, 0.75 mm. The flows at Salem are lower in magnitude than the upstream flow gage at Pen. The decrease in flow is due to the two year-round diversion canals in downtown Salem that are designed to eliminate flooding in Salem.

Figure 11. Seasonal Flow Variation for Mill Creek at Pen and Mill Creek at Salem during the overlapping time period of 1940 to 1956.



Further comparison of the overlapping flow records for each flow gage examined the peak flow records, Figure 12. Peak flow history allows for identification of the magnitude and frequency of high flows. The calculated 1.5 year peak flow for Mill Creek at Pen, 24.07 mm, is almost three times the 1.5 year peak flow calculated for the downstream flow gage at Salem, 7.38 mm. The frequency of peak flow events for both flow gages occurs during similar time periods. For example, in 1950 there is an increase in the annual peak flow and then again in 1956 at both flow gages.

Figure 12. **Peak Flow for Mill Creek at Pen and Mill Creek at Salem during the overlapping time period of 1940 to 1956.**



The Flow Analysis Tool spreadsheet was then used to develop a relationship between the two flow gages in Mill Creek. The overlapping flow data, drainage area, and period of record dates were entered into the spreadsheet. The spreadsheets summary flow output tables were used to calculate a flow ratio for each exceedance probability interval. This is done by dividing the flow values from the expired flow gage, Mill Creek at Pen, by the corresponding real-time surrogate flow gage, Mill Creek at Salem (Table 5).

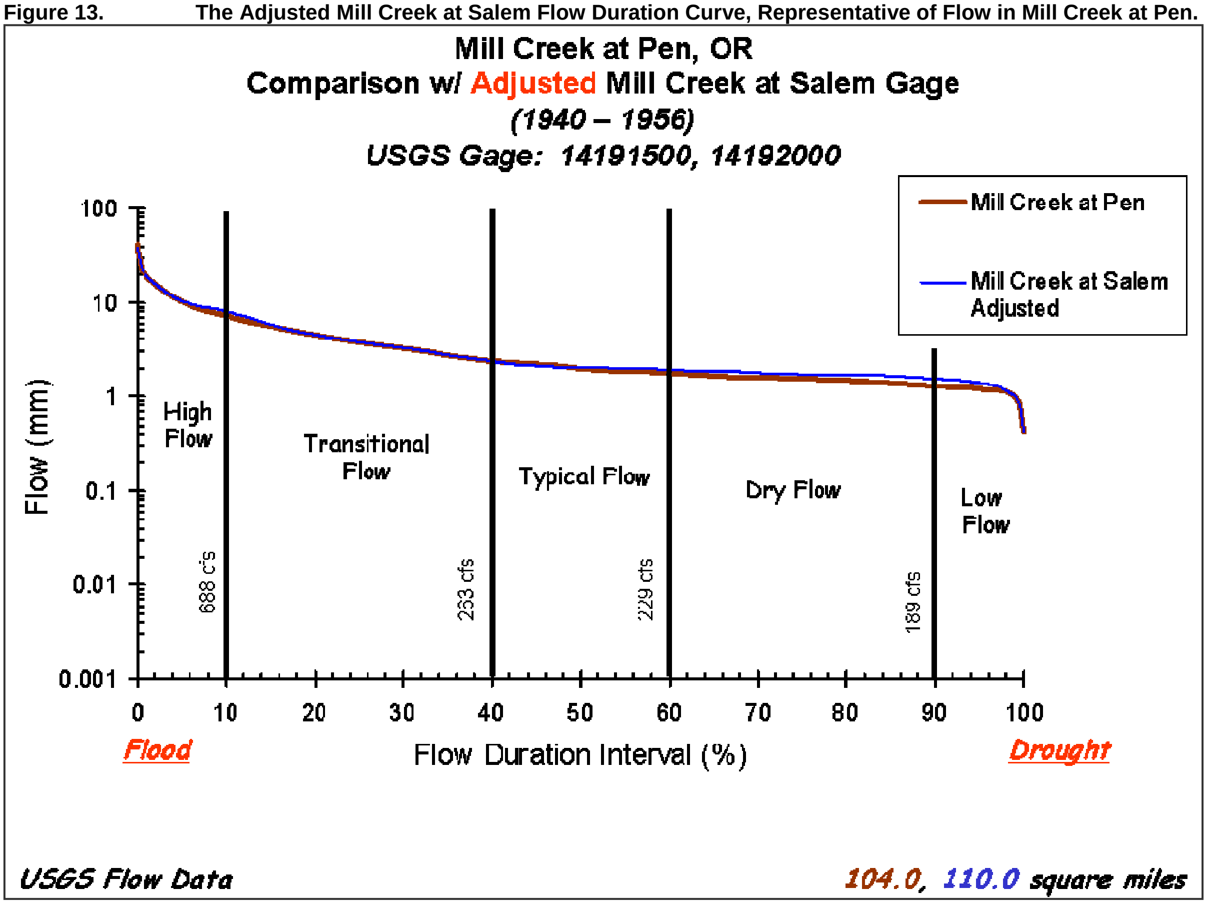
Table 5. Flow Ratio for Flow Values during Common Dates of Operation (1940 to 1956)

Exceedance Probability EP (%)	Mill Creek at Pen mm	Mill Creek at Salem mm	Adjustment Ratio *(Pen/Salem)=*
0.01%	38.9775	9.5390	4.0861
0.10%	30.5709	7.7666	3.9362
1%	19.0745	5.6556	3.3727
5%	10.2502	3.9331	2.6061
10%	7.0848	3.0915	2.2917
15%	5.5407	2.5419	2.1797
20%	4.5688	2.0610	2.2167
25%	3.8149	1.7175	2.2212
30%	3.2072	1.4513	2.2099
35%	2.7426	1.2280	2.2334
40%	2.4052	1.0305	2.3340
45%	2.1709	0.8759	2.4783
50%	1.9892	0.7471	2.6625
55%	1.8620	0.6355	2.9301
60%	1.7621	0.5582	3.1568
65%	1.6804	0.4981	3.3737
70%	1.6077	0.4466	3.6002
75%	1.5441	0.4036	3.8257
80%	1.4805	0.3521	4.2050
85%	1.3988	0.2920	4.7907
90%	1.2989	0.2319	5.6019
95%	1.1899	0.1632	7.2925
99%	1.0082	0.0748	13.4715
100%	0.4087	0.0301	13.5989

The calculated flow ratios are used to adjust each daily flow value recorded at the surrogate flow gage, Mill Creek at Salem. This ratio adjustment will calculate the stream flow representative of those that would have occurred at the Mill Creek at Pen flow gage, both during the period of overlapping operation and the entire period of record for Mill Creek at Salem.

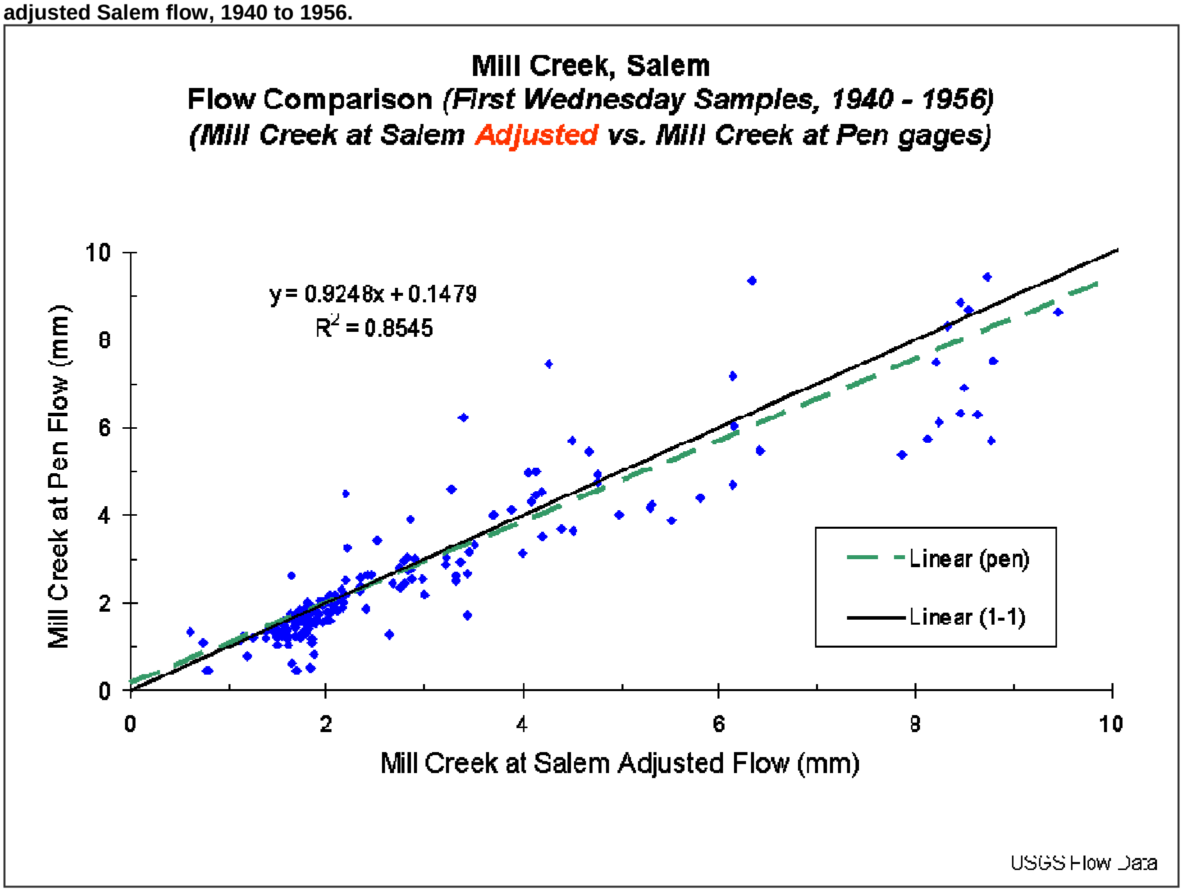
Once the flow values for the surrogate real-time flow gage, Mill Creek at Salem, have been adjusted by the calculated flow ratios (above), a new flow duration curve is calculated to derive a real-time flow regime for the expired flow gage, Mill Creek at Pen. The new flow duration curve for Mill Creek at Pen (expired flow gage) is overlapped onto the real-time flow gage at Salem in Figure 13. The adjusted flow duration curve for Mill Creek at Salem was used to develop the load duration curve for Mill Creek at Pen, as used in the Middle Willamette Bacteria TMDL, see Chapter 7.

Figure 13. The Adjusted Mill Creek at Salem Flow Duration Curve, Representative of Flow in Mill Creek at Pen.



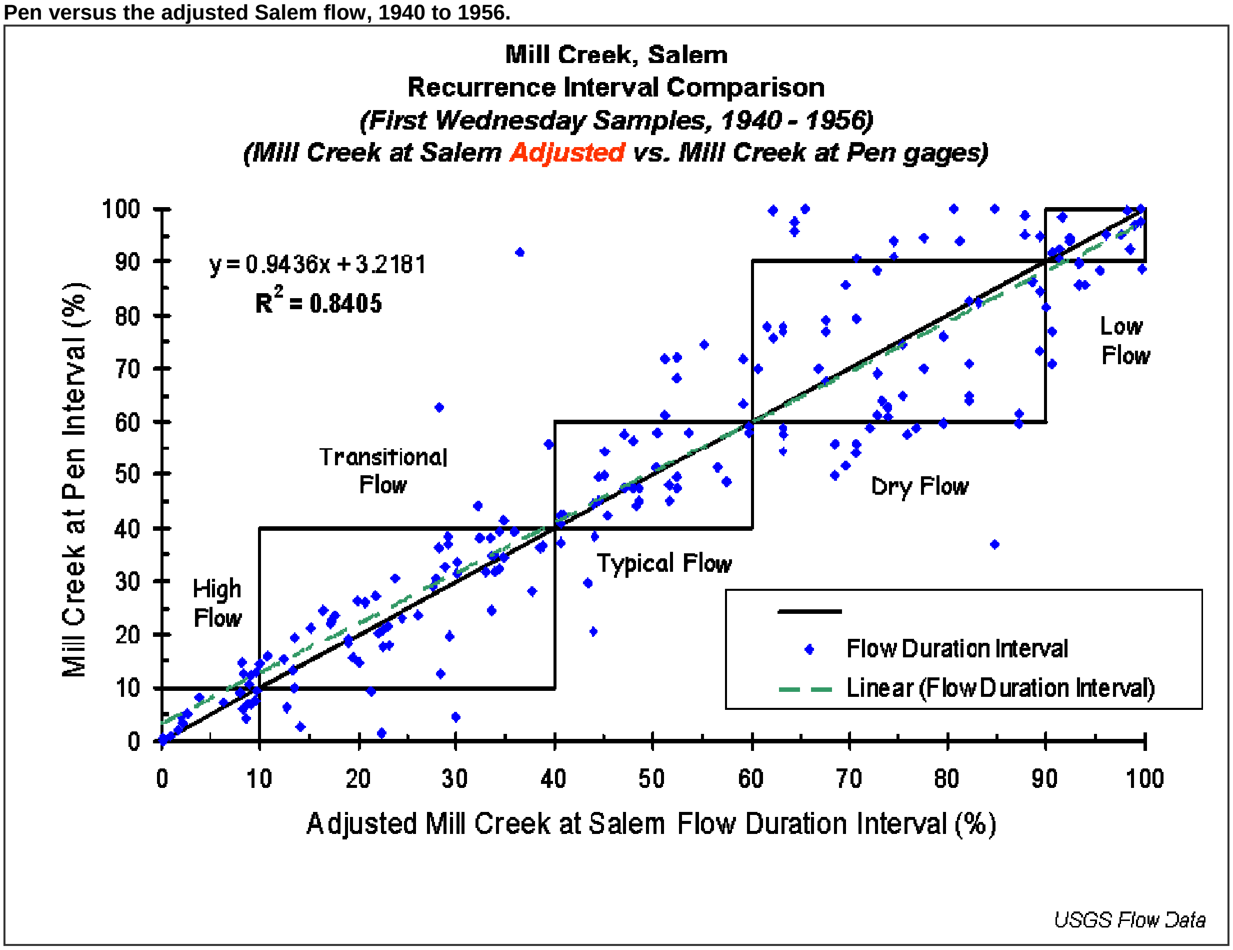
The output from the adjusted surrogate flow gage, at Salem, is compared to the output flow from the historic flow gage, at Pen, to determine if the extrapolated flows are statistically similar to the historic flows. This analysis was done as a quality assurance measure to verify the statistical validity of the adjusted flows. The statistical validity of the adjusted flows have been verified by calculating the linear regression of the flow for each first Wednesday of the month for the overlapping period of record. The flow values from the adjusted flow gage at Salem were plotted against the historic flow values recorded at the flow gage at Pen. The resulting flow comparison regression graph, Figure 14, has a calculated linear R-squared of 85%.

Figure 14. Flow Comparison of Historic First Wednesday of the Month Flows for Mill Creek at Pen versus the adjusted Salem flow, 1940 to 1956.



A flow recurrence interval for the first Wednesday subset flow data, above, was also developed, Figure 15. The flow recurrence interval plot, below, compares the timing of the flow recorded at Pen to the flow calculated by the adjusted flow gage at Salem. The regression plot has a calculated linear R-squared value of 84%. Data points plotted within each flow box represent a similar flow recurrence within each of the five established flow regimes (high, transitional, typical, dry, low).

Figure 15. Flow Recurrence Interval Comparison of Historic First Wednesday of the Month Flows for Mill Creek at Pen versus the adjusted Salem flow, 1940 to 1956.



BACTERIA MODELS

QUAL2E Model

QUAL2E is a steady state, one-dimensional, first-order decay-rate model. It allows for multiple waste discharges and tributary flows. The model can simulate up to 15 water quality constituents. Because the model is steady state, it is limited to the simulation of time periods in which the stream flow and waste loads are constant (USEPA 1987). The channel geometry and discharge coefficients for the QUAL2E model are based on a model developed by ODEQ and Tetra Tech as part of the Willamette River Basin Water Quality Study (1993). Model development was funded by ODEQ. The decay rate of 1.3 / day was chosen to be consistent with bacteria modeling of the Willamette River for design of the Portland CSO project (Limno-Tech 2001).

The reasonable worst case scenario was defined as average January flows from the tributaries and the 90th percentile concentration of *E. coli* based on data collected from during the Fall-Winter-Spring period (Tables 6 and 7). ODEQ ambient monitoring network provided *E. coli* data for tributaries and the main stem calibration sites. These sites are distributed throughout the state and provide the basis for long term assessment of water quality on the statewide scale. Tributary monitoring sites were generally located near the mouths of rivers and there were a sufficient number in the Willamette Basin to accommodate TMDL analysis. Most sites were sampled monthly or every other month between January 1996 and April 2003. The average January flows were derived from the entire periods of record of the USGS stream gage network.

Certain tributaries did not have co-located gage and water quality monitoring sites at their mouths. The *E. coli* concentration for the headwaters was a flow-weighted average between the Coast and Middle Forks of the Willamette River. Likewise, the *E. coli* concentration for the Molalla River was a flow-weighted average of the Molalla and Pudding Rivers because no sampling exists downstream of their confluence. Average concentrations of *E. coli* in the North and South Santiam Rivers were weighted based on drainage area because flow gages were not available. An average of January flow for the mainstem and tributaries was based on USGS gages throughout the basin. The greatest average monthly flow for the Willamette River at Salem gage (USGS #14191000) occurs in January. This gage has operated continuously since 1909.

Table 6. Metrics used in the QUAL2E Willamette River bacteria model

Willamette River Sampling Site	RM	ODEQ Site #	FWS *E. coli* samples (count	90th percentile of FWS *E. coli* (col / 100 ml)	Flow (cfs)
SP&S Bridge	7	10332	28	318	
Hawthorne Br.	13.2	10611	61	180	65200
Canby Ferry	34.4	10339	28	168	
Newberg	48.6	10342	61	160	
Wheatland	71.9	10344	26	87	
Salem	84.0	10555	60	136	46440
Albany	119.3	10350	60	134	27970
Corvallis	131.4	10352	57	132	
Harrisburg	161.2	10355	58	51	21200
Springfield	185.3	10359	23	31	

Table 7. Metrics used in the model for the tributaries

Tributary	River Mile of Confluence	USGS Gage #	ODEQ Site #	Flow (cfs)	FWS *E. coli* samples (count)	FWS *E. coli* 90th percentile (org / 100 ml)
Coast Fork Middle Fork	187	14157500 14152000	11275 10386	10649	27 27	55[A]
McKenzie R	174.8	14163900 14165000	10376	6317	43	40
Long Tom R	145.9	14170000	11140	2100	31	540
Mary's R	132.1	14171000	10373	1192	79	215
Calapooia R	119.5	14173500	11180	2276	34	522
North Santiam R South Santiam R	108	14189000	17092 10366	14270	45 28	60[B]
Luckiamute R	107.5	14190500	10658	2236	7	427
Rickreall Cr	88.1	14907000	10364	392	8	357
Mill Cr*	83.6	14192000	28961	272	12	862
Yamhill R	54.9	14194150 14197000	10363	5510	40	908
Molalla R Pudding R.	35.7	14200000 14202000	10637 10363	5156	28 28	272A
Tualatin R	28.4	14207500	10456	3883	41	228
Clackamas R	24.8	14211000	11233	7019	43	96
Johnson Cr	18.5	14211550	11321	65	32	976

Notes: (A) concentrations were flow-averaged from two monitoring sites.
(B) concentrations averaged from two monitoring sites, weighting by drainage area
(C) E. coli sampled at Front St. Bridge, Salem; Data collected by City of Salem.
FWS = Fall-Winter-Spring, the period from October through May.

This model was chosen for the middle and upper segment (RM 18 to 148) of the listed Willamette River, upstream of Willamette Falls, for the following reasons:

- A QUAL2E model of the Willamette River had previously been established.
- The model allows for bacteria decay thus simulating increases in loading capacity downstream.
- The model can simulate the effects of tributary loads on the mainstem Willamette River.

ODEQ acknowledges that using a steady-state model imposes several limitations on the analysis, such as:

- Statistical representations of *E. coli* concentrations and flow are used rather than a time series of measurements.
- The not-to-exceed portion of the bacteria standard (no sample greater than 406 *E. coli* / 100 ml) cannot be addressed.
- The model cannot account for sewer overflows occurring at different times.
- No attempt was made to quantify loading below river 50 due to the temporally and spatially variable loading patterns for which a steady state, 1-dimensional model is not appropriate.

PULSEQUAL Model

Far-field *E. coli* concentrations in the lower Willamette River, downstream of Willamette Falls to the mouth of the river, were simulated with PULSEQUAL (City of Portland, 1999b and Limno-tech, Inc. 2001). The model is a combination of baseline and "pulse" sub-models that are one-dimensional, averaging both in the lateral and vertical directions. The pulse sub-model applies a closed-form solution to an impulse dispersion model for each transient load and superimposes their movement onto baseline calculations. The model simulates hourly *E. coli* concentrations over a six year period of diverse hydrologic conditions. The model output is discretized into 0.4 mile segments. Upstream boundary *E. coli* concentrations were determined using a Monte Carlo simulation which was based on the statistical properties of the Waverly County Club monitoring site (RM 17.9). The model was calibrated and validated using weekly *E. coli* data from December 1995 through June 1997 at five sampling locations. Different loading scenarios were simulated from 1982 to 1987 in order to capture a range of hydrologic conditions.

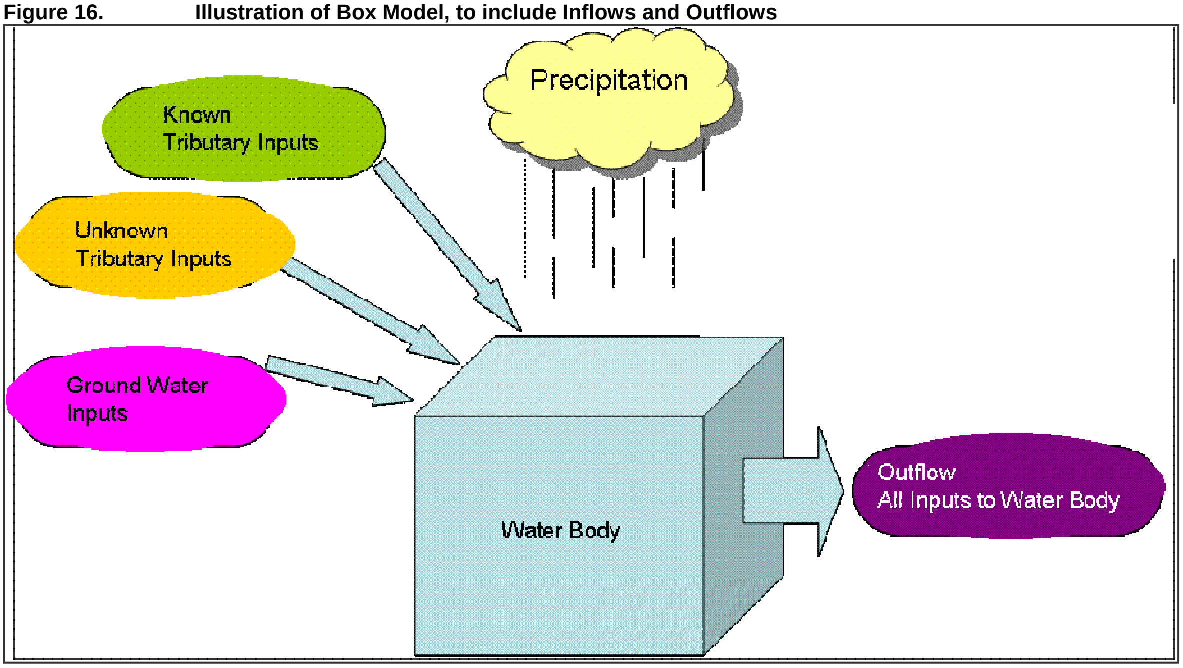
The upstream boundary *E. coli* concentration of the PULSEQUAL model was reduced to meet the log mean criterion of 126 *E. coli* organisms/100 ml during the period of model simulation. The TMDL calls for reduction of upstream sources during the high flow period while no reductions are needed during the lower flow periods. To best simulate this pattern of reduction, the log of the individual *E. coli* concentrations were reduced by 18% so that the maximum 30-day log mean was less than 126 *E. coli* organisms/100 ml. Reduction of the log of *E. coli* concentrations allowed for larger reductions of higher concentrations and smaller reductions of lower concentrations.

The City of Portland collected *E. coli* samples from the Willamette River from December 1995 to April 2003 between RM 1.1 and 20 at six monitoring sites. Model specifics and calibration can be found in City of Portland document titled "Water Quality Assessment of Lower Willamette River, Willamette River CSP Predesign Project", 1999b. Bacteria samples were collected approximately weekly from April 1995 to June 2000, twice a month from July 2000 to October 2002, and monthly from November 2002 to April 2003. Each site was sampled at three locations: east, middle and west. No duplicate sample results were provided to ODEQ, and hence the ODEQ methodology for quality assurance checks could not be applied. However, using the east and west sample locations, the log difference with the middle sample could be computed. For example, the Waverly Country Club sample location is upstream of the CSO impact, so lateral difference in concentrations should be less than further downstream. The average log difference between samples was 0.26 which is less than the 0.5 threshold for duplicate samples to be graded "A" or "A+". Eleven percent of the log difference exceeded the 0.5 threshold and hence would have been graded "B" if they had been duplicate samples. Based on the size of the dataset and the analysis above, ODEQ used the City of Portland data, in conjunction with the ODEQ data, to develop the mainstem Willamette River TMDL (see Chapter 2).

BOX Model

A box model is used to assess the source contributions leading to violations within a reservoir or lake water body. The model is a mass balance of upstream conditions on a water body. A box model is developed to represent the flow and bacteria concentrations typical of conditions in the water body. Bacteria loads are calculated for each tributary flowing directly into the water body. Overland runoff from precipitation is also included in the Box Model. Die-off is not considered in the model. The Box Model calculates the load contributed to the water body by external inputs. An illustration of the model assumptions is presented in Figure 16.

Figure 16. Illustration of Box Model, to include Inflows and Outflows



Upper Willamette Subbasin: Fern Ridge Reservoir

The Fern Ridge Reservoir Box Model was created to compare bacteria loads entering the reservoir with those exiting at the dam outflow point. The end goal of the model is to calculate the contributions of the various inputs responsible for *E. coli* water quality violations in the reservoir. *E. coli* data collected during a storm survey in the Long Tom Watershed during December 11th to 15th, 2004 was used for the box model development. The percent reduction for the reservoir was calculated by comparing the log mean of storm data gathered in the Long Tom River at Alvadore to the 126 log mean criterion.

Flow and bacteria concentrations that flow into the Reservoir were included in the box model. Model inputs included concentrations and flows from the Upper Long Tom River, the Amazon Diversion Channel, Coyote Creek, precipitation, groundwater, and small streams flowing directly into the reservoir. Average December in-stream flows were used to calculate the bacteria load for the box model. Average December precipitation entering the reservoir was calculated by multiplying the surface area of the reservoir by the average December precipitation. The reservoir volume per day was converted to cubic feet per second (cfs) to be comparable with stream flow values.

The December stream flows for Coyote Creek were averaged from the data collected at USGS flow gage # 14167000 near Crow Road. This flow gage was operational during the period 1940 to 1987. The Coyote Creek flow data is available on-line at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14167000

The December Amazon Creek Diversion flows were averaged from data collected at the USGS flow gage # 14169400. The Amazon Creek Diversion was operational from 1966 to 1968. The flow record for Amazon Creek Diversion is available on-line at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14169400

The December flows for the Long Tom River near Noti were averaged from the data collected at the USGS flow gage # 14166500 near Noti. This flow gage has been operational since 1935. It is a real-time operational flow gage. The flow record can be accessed on-line at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14166500

The Fern Ridge Reservoir output December flows were averaged from data collected at the USGS flow gage # 14169000, Long Tom River near Alvadore. This flow gage has been operational since 1939. It is a real-time operational flow gage. The December flows from 1963 to 2002 were averaged for the Box Model. The flow record for this flow gage is available on-line at:
http://waterdata.usgs.gov/or/nwis/nwisman?site_no=14169000

The December precipitation was averaged from data collected at the Eugene WSO Airport climate station # 352709 from 1966 to 2002. This climate station has been collecting precipitation data since 1939. Information regarding this station is available on-line at: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?oreuge

Stream flow data was unavailable for some of the small streams and groundwater that directly flows into the reservoir. The difference between the average input flow and average output flow was calculated and assigned to the small stream and groundwater source category.

The log mean of the *E. coli* storm data for each stream flowing into the Reservoir was input as the bacteria load for the Box Model. The *E. coli* load was calculated by converting flow from cfs to liters per day then multiplying by the log mean *E. coli* concentration after converting it from counts per 100 milliliters to counts per liter. *E. coli* data was not available for the small streams and groundwater. The average of the log mean *E. coli* values for Long Tom, Coyote, and Amazon creeks was assigned to the small streams and groundwater source category. Input and output values for the model are presented in Table 8.

Table 8. Summary of Fern Ridge Box Model Values

Water bodies	Ave. December Flow (cfs)	E. coli Log Mean (counts/100ml)	E. coli (Counts/Day)	Percentage of Total
Long Tom at Noti (Input)	471.31	196	2.26E+12	9%
Coyote Creek at Crow Rd. (Input)	459.30	480	5.40E+12	21%
Amazon Cr. Diversion Channel (Input)	55.96	1774	2.43E+12	9%
Precipitation (Input)	108.02	0	0	0%
Small Streams and Groundwater (Input)	107.04	551	1.44E+12	6%
Unknown (Input)	0.00		1.41E+13	55%
Long Tom at Alvadore (Output)	1201.62	871	2.56E+13	100%

E. coli inputs from known water bodies equate to 45% of the output of *E. coli* from the reservoir. The remaining 55% could be produced from a variety of sources that influence *E. coli* populations in the reservoir directly.

Event Mean Concentration (EMC) Model

A GIS-based model was used to evaluate bacteria loading to the watersheds. The model estimates upland runoff volume using the Soil Conservation Service (SCS) method and applies Event Mean Concentrations (EMCs) to estimate relative bacteria loading from the various land uses within the individual watersheds. Watershed composite maximum bacteria loads are then calculated to meet the state water quality standard concentration.

Soils (SSURGO) (slope and hydrologic soil group), land use (USGS) and watersheds were the geographic databases used for this modeling exercise. The databases were overlaid in ArcView to create a composite GIS database which was used for estimating flow volume and bacteria die-off rate as function of travel time, and bacteria load.

The bacterial die off rate during overland flow was estimated based on the travel time of the water. The travel time of water (hydrologic time of concentration) was estimated using a kinematic wave equation (Chow et al, 1988):

Travel Time (minutes) = T = $(6.93L^{0.6}n^{0.6})/(i^{0.4} S^{0.3})$

Where:

- L = Slope length (meters)
- n = Manning's n
- i = Rainfall Intensity (mm/hr)
- S = Slope (m/m)

The generalized slopes were derived from the SSURGO soils data. The Manning's n values were based on land uses (Chow et al, 1988). The slope length was entered as a constant (2,000 meters).

Decay is based on the first order decay equation. Coliform bacteria are often modeled as part of water quality studies; first-order decay has been a very good assumption in many studies, with coefficients ranging from 0.0004 to 1.1/hour (Huber 1993). Reported *E. Coli* decay rates range from 0.08 to 2.0 /day (Thomann and Mueller, 1987).

The model assumes a decay rate of 1.0 /day. The decay rate is expressed as the percentage of bacteria that die in the runoff during its time of travel. For example, using the assumed decay rate of 1.0/day, approximately 33% of the bacteria die in runoff with a 4 hour travel time.

First order decay (Boyce and DiPrima, 1977):

$$\frac{N_t}{N_o} = 10^{-kt}$$

Where:

- N_t = number of bacteria at time t
- N_o = number of bacteria at time o
- t = time in days
- k = first order decay rate constant

The first order decay rates were input as 1.0 in the model and typically range between 0.01 and 2.0 (Moore, 1982).

The runoff volume was estimated using the Soil Conservation Service (SCS) runoff depth estimation (SCS Technical Release 55, June, 1986):

$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$

Where,

Q = runoff depth in inches
P = rainfall in inches
S = storage parameters = $\frac{1000}{CN} - 10$
CN = curve number which is a function of land use (see McCuen, 1998 for Curve Numbers)

Because the model is spatially-based, calculations were performed for each polygon within each watershed. Calibration coefficients were then applied to the entire watershed and flow volume was calculated at the outlet of the watershed.

Event Mean Concentrations (EMCs) are flow weighted average bacteria concentrations during a storm event. The EMCs were also used to study loading to the Corpus Christi Bay System in South Texas (Quenzer, 1998). The EMCs are based on studies done by USGS and many other organizations. EMC estimates were used to assess the relative contributions from the different land uses.

The general literature indicates relatively minimal bacteria contributions from forested and range lands. Much larger values are reported for urban and agricultural areas.

Assumed relative differences from land use sectors are characterized by literature values for Event Mean Concentrations (EMCs) (values were compiled from many studies done by the USGS and other organizations). For example, the agriculture bacteria EMC is 1.3 times that of the residential/urban EMC.

EMCs were applied to each land use category. The model was calibrated to in-stream storm sampling *E.coli* concentrations at the outlet of the watershed.

Upper Willamette Subbasin: Calapooia River Watershed

Bacteria was modeled for the Calapooia River Watershed to address the Calapooia River winter 303(d) listings. The hydrology was calibrated to the measured discharge values collected at Calapooia River at Queen Road, the outlet of the watershed. Uncertainty exists in all modeling activities. The hydrology model was calibrated to measured stream flow data collected at Calapooia River at Queen Road. Precipitation data was collected at Eugene and Foster Dam and averaged. The model was calibrated by adjusting the SCS curve numbers to fit the Calapooia River stream flow. This is reinforced by the Calapooia Watershed sampling during 2002 and 2003. Forested reaches in the upper Calapooia watershed (e.g Calapooia River at McClun Wayside) have low concentrations of bacteria, whereas the lower portion of the watershed (e.g. Oak Creek and lower Calapooia River) exhibit relatively high concentrations.

Upper Willamette Subbasin: Luckiamute River Watershed

Bacteria was modeled for the Luckiamute River Watershed to address the Luckiamute River winter 303(d) listings. The hydrology was calibrated to the Luckiamute River at Helmick State Park gage. The outlet of the watershed was Luckiamute River at Lower Bridge. Uncertainty exists in all modeling activities. The hydrology model was calibrated to measured stream flow data collected at Luckiamute River at Helmick State Park gage. Precipitation data was collected at Salem, Oregon airport. The model was calibrated by adjusting the SCS curve numbers to fit the Luckiamute River stream flow. This is reinforced by Luckiamute Watershed sampling during 2001 and 2002. Forested streams in the upper Luckiamute watershed (e.g N.F. Pedee Creek) have low concentrations of bacteria, whereas the lower portion of the watershed (e.g. Soap Creek) exhibit relatively high concentrations.

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