APPENDIX 1: BACTERIA TMDL SUPPLEMENTAL INFORMATION

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SECTION 1 – LABORATORY BACTERIA ANALYSIS METHODS

The majority of data analyzed for development of this TMDL was of *E. coli* concentrations, though fecal coliform data are still collected for estuarine waters to assess the potential health threat of consuming harvested shellfish. The methods of bacterial analysis have changed over time, with some DEQ 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 this report.

For a number of years, DEQ 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). *E. coli* sampling currently uses a 6-hour holding time when a local lab is available and practical otherwise river samples are analyzed within a 24-hour period. EPA has indicated in letter to DEQ dated July 1, 2004 that “in our review of both this specific instance, (collection of data for the Umpqua bacteria TMDL) and in its general operations EPA has found Oregon DEQ data collection procedures to be sound and appropriate for the uses to which they are applied”.

DEQ 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 have no duplicate samples taken. DEQ 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

SECTION 2 – 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. This example uses the USGS flow gage at Umpqua River at Brockway and the DEQ ambient monitoring site South Umpqua At Hwy 42 (Winston). Both are located approximately at river mile 21.2.

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 January 1, 1990 until January 13, 2003 (Table 1). The exceedence probability (*EP*) for each flow was computed by:

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

where n is number of flow measurements. The “percent of days flow exceeded” is the exceedence probability multiplied by 100 (Figure 1).

Table B-1. Example 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	16739	0.99994

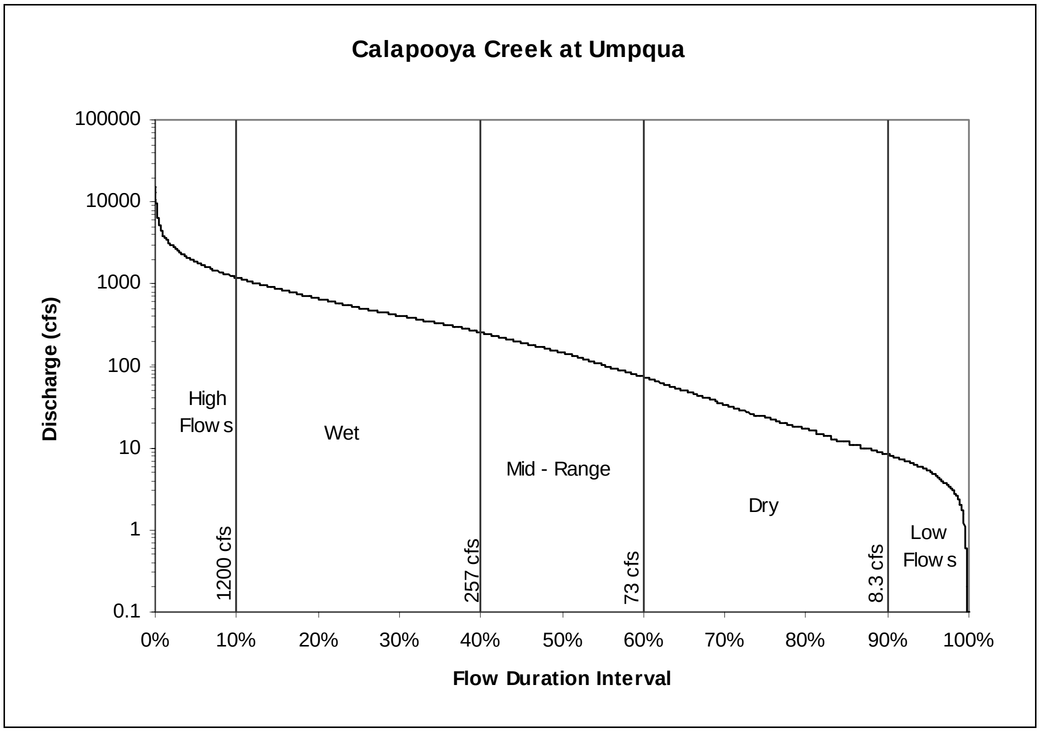

Figure B-1. Flow duration curve

The flow duration curve is transformed into a load duration curve by multiplying the flow by the water quality standard and a conversion factor. The computed load is the flow dependent loading capacity. For example, the log mean recreational contact standard for bacteria is 126 organisms per 100 milliliters (org / 100 ml), so the loading capacity is:

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

The loading capacity is then plotted against the corresponding *percentage of days flow exceeded*. There are two line representing the two numeric targets: log mean of 126 org / 100 ml and no samples exceeding 406 org / 100 ml. The loading capacity increases with increased flow because of the increased assimilative capacity of the river.

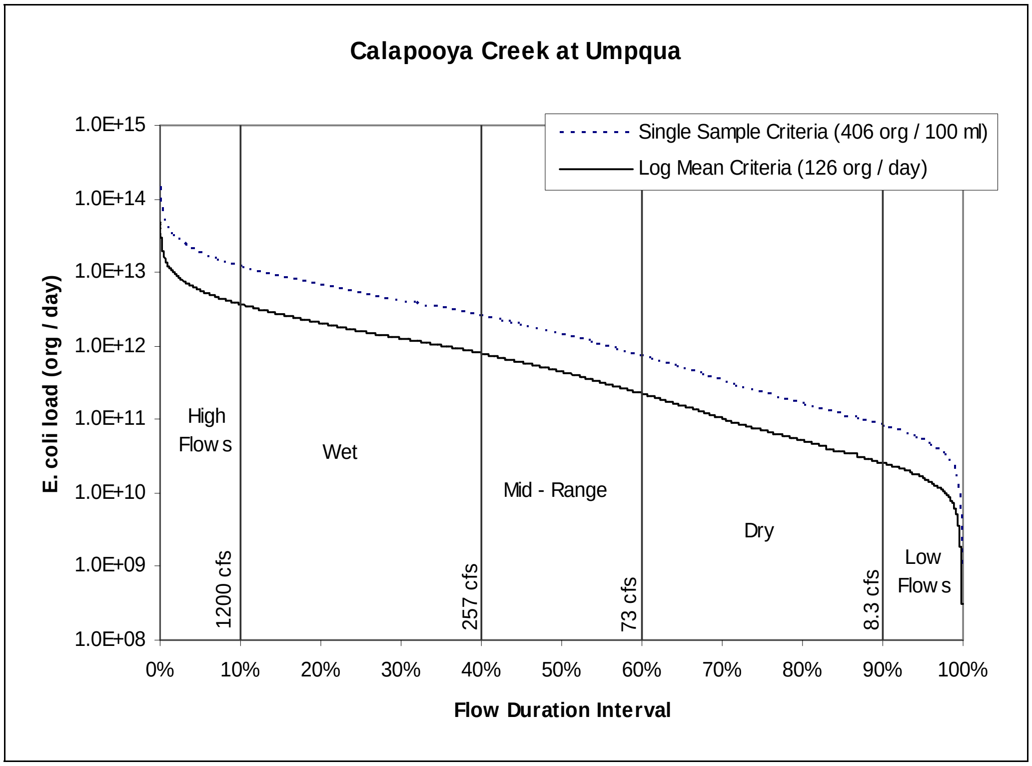

Figure B-2 . Load Duration Curve. Plot shows the flow based *E. coli* loading capacity for the South Umpqua at Winston. A low percentage value (on the left) corresponds to a higher flow, and hence a greater assimilative capacity. Conversely, a high percentage value corresponds to a low flow and a lower loading capacity.

Measured concentrations of *E. coli* are converted into loads using the equation above and flows from the stream gage. The “event loads” are plotted along with the standard lines to assess current conditions (Figure B-3).

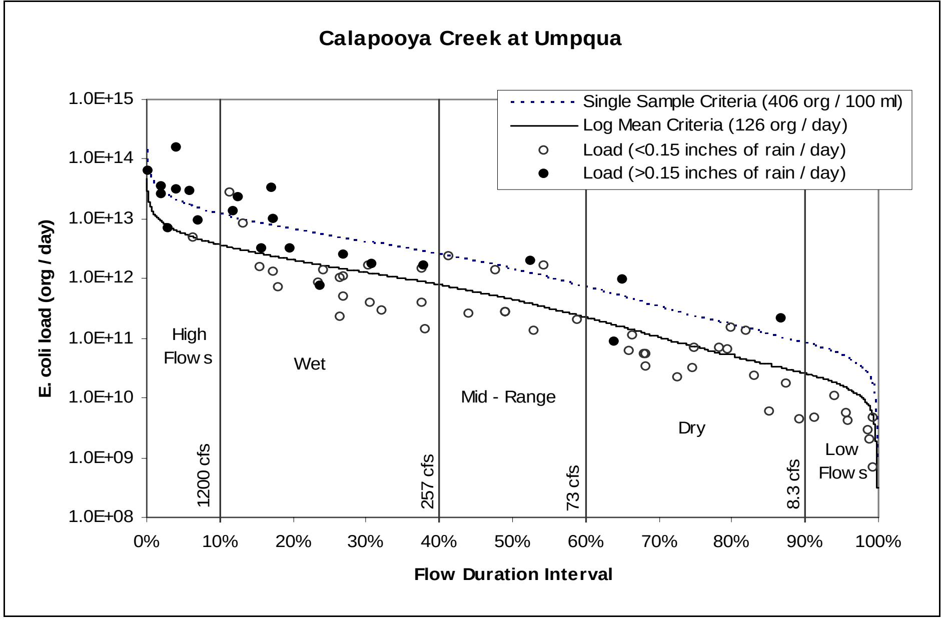

Figure B-3 . Load duration curve with measured daily loads. Measured loads above the loading capacity of 406 org/ 100 ml (orange line) exceed water quality standards.

Load duration curves and measured loads are summarized by range of flows and the TMDLs are computed (Table B-2 and Table B-3 for example). A generalized loading capacity for each of the five flow periods was computed by taking the log-mean of calculated loading capacity for each day within that period. The log-mean of the observed *E. coli* loading within each of the flow periods was compared with the loading capacity of that flow period.

Table B-2. Calculating the TMDL by flow regime.	
	Flow Regime
Current Loading	Log mean of observed loads within flow regime
% reduction	= (1 – TMDL / current) * 100
Loading Capacity (LC)	Log mean of daily load capacity within flow regime
Load Allocation	= LC – WLA – MOS
Waste Load Allocation	= concentration allowed under bacteria standard
Maximum Waste Load	= Sum of point source loading
MOS	= LC * 0.05
TMDL	=LC=Log mean of flow capacities within range of flows

Table B-3. Example from Calapooya Creek					
	Range of Flows				
	High Flows	Wet	Mid-Range	Dry	Low Flows
Loading Capacity	6.44×10^{12}	1.64×10^{12}	4.36×10^{11}	7.40×10^{10}	1.31×10^{10}
Current Loading	2.39×10^{13}	1.76×10^{12}	5.55×10^{11}	5.27×10^{10}	3.45×10^{9}
% reduction	73%	7%	21%	0%	0%
Waste Load Allocation (org./100 m.)	126	126	126	126	126
Maximum Waste Load	1.43×10^{10}	1.43×10^{10}	1.43×10^{10}	0	0
Load Allocation	6.11×10^{12}	1.54×10^{12}	4.00×10^{11}	5.27×10^{10}	3.45×10^{9}
MOS	3.22×10^{11}	8.19×10^{10}	2.18×10^{10}	2.12×10^{10}	9.62×10^{9}
TMDL	6.44×10^{12}	1.64×10^{12}	4.36×10^{11}	7.40×10^{10}	1.31×10^{10}

Modified Load Duration Curve

Daily fecal coliform load in rivers can be computed from measured concentrations and stream flow. Due to the influence of tides on stream depth and flow direction, stream flow is not normally measured in tidal influenced areas. Furthermore, dilution of the river water with seawater increases the loading capacity in an estuary. A methodology was developed to determine loading capacity that uses a physically based hydrologic model to estimate the daily volume of fresh water delivered to the estuary and empirical relationships to estimate dilution using salinity as a conservative tracer.

A hydrologic model was used to estimate the daily volume of fresh water delivered to the Umpqua River at Hwy 101 and Leeds Island and at the mouths of Scholfield Slough and Smith River. Soil and Water Assessment Tool (SWAT), which was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS),computes the land phase hydrology in multiple subbasins located within the watershed and then routes water through a river network (Neitsch et. al. 2001 and Bacteria Modeling Appendix, this document). Smith River, Elk Creek, Scholfield Slough and the other tributaries to the Umpqua below Elkton were modeled. The flow gage on the Umpqua near Elkton was used as an input to the model. Flow gages on Elk Creek near Drain, Smith River near Drain, West Fork of the Smith River, and Vincent Creek were used to estimate the parameters in the model for Muskingum Routing and groundwater percolation (see Bacteria Modeling Appendix). The coefficients used for this model are the same coefficients used to model the hydrology of two other coastal basins: the Nehalem and Necanicum Rivers (DEQ, 2003). The same coefficients were chosen because all three basins are in the Coast Range ecoregion, and therefore have similar characteristics relating to groundwater.

Dilution of river water with seawater increases the loading capacity of the bay assuming that the seawater has a lower concentration of fecal coliform than the river water. Salinity can be used as a conservative tracer because its concentration in river water and in seawater can be estimated. The measured salinity of river water is 0 parts per thousand (ppt) and the salinity of seawater is approximately 34 ppt, based on the maximum recorded measurement at the mouth of the estuary. Decreasing concentration with proximity to the mouth and the inverse relationship between salinity and fecal coliform concentrations support the assumption of dilution by seawater in the Umpqua estuary.

Based on the assumption that the bacteria load is overwhelmingly associated with fresh water sources, the load of fecal coliform per day can be computed for each sampling event by the following equations:

$$Daily\ \ Load = V_t * C * 10{,}000$$

$$V_t = V_r + V_s$$

$$V_r = Q * 86{,}400 * 0.0283$$

$$V_s = \frac{V_r}{\left(\frac{S_s}{S_t} - 1 \right)}$$

V_t = volume daily total (m^3)
C = concentration of fecal coliform (org. / 100 ml)
V_r = volume of river water (m^3)
V_s = volume of seawater (m^3)
Q = river flow (cfs) from hydrologic model
S_s = salinity of seawater (35 ppt)
S_t = measured salinity (ppt)

The loading capacity was computed in a similar manner to event loads using flow from the hydrologic model and empirical relationships between flows and salinity (Table 4 and Figure 5, for example). The exceedence probability of 0.5 corresponds to a fresh water flow of 6950 cfs and a calculated salinity of 4 ppt (Figure 6). Thus the daily median (14 org. / 100 ml) and 90th percentile (43 org. / 100 ml) loading capacities are 2.75 x 1012 and 8.44 x 1012 fecal coliforms, respectively. An exceedence probability of 0.1 corresponds to 25,240 cfs and hence a median and 90th percentile loading capacity of 8.64 x 1012 and 2.65 x 1013 fecal coliforms, respectively.

Table B-4. Salinity Regression

Site	Salinity (ppt) as a function of Q (cfs)	R2	Salinity = 0 if Q greater than (cfs)
Umpqua R. at Leeds Is.	-13.8 LOG (Q) + 57.4	0.79	14,840
Umpqua R. u/s Reedsport	-12.7 LOG (Q) + 48.8	0.75	6,980
Scholfield Sl. at mouth	-6.1 LOG (Q) + 14.3	0.75	210
Smith R. at Butler Creek	-6.0 LOG (Q) + 21.0	0.67	3,320

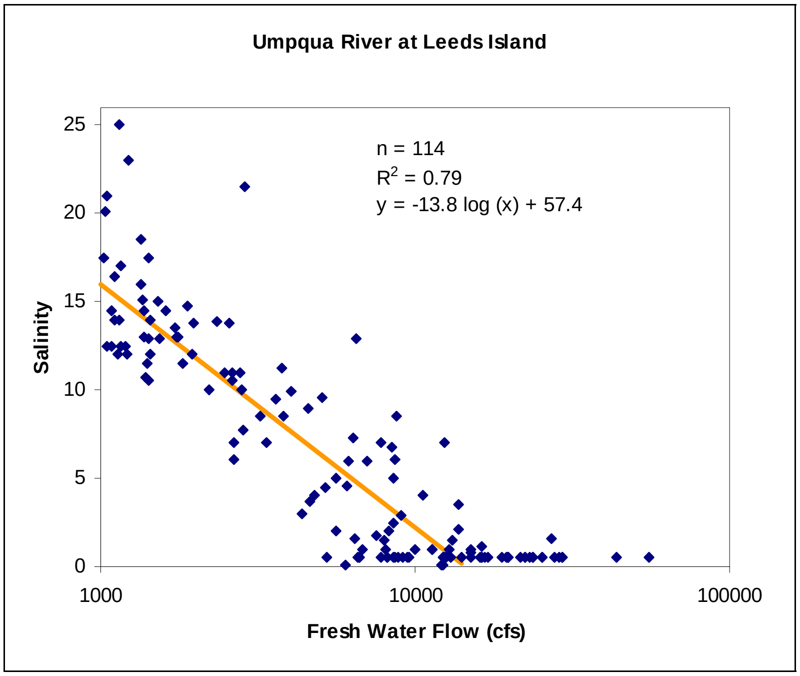

Figure B-5. Regression of salinity to fresh water flow derived from hydrologic model.

The strong relationship between predicted fresh water flow in the estuary and measured salinities helps validate the derived hydrology (Figure B-5). Daily variations in salinity due to tidal reversals likely account for the remainder of the noise in the dataset.

The effect of dilution with ocean water is expressed during low flows on the load duration curve. The loading capacity does not decrease at low flows relative to the South Umpqua load duration curve (Figure B-6).

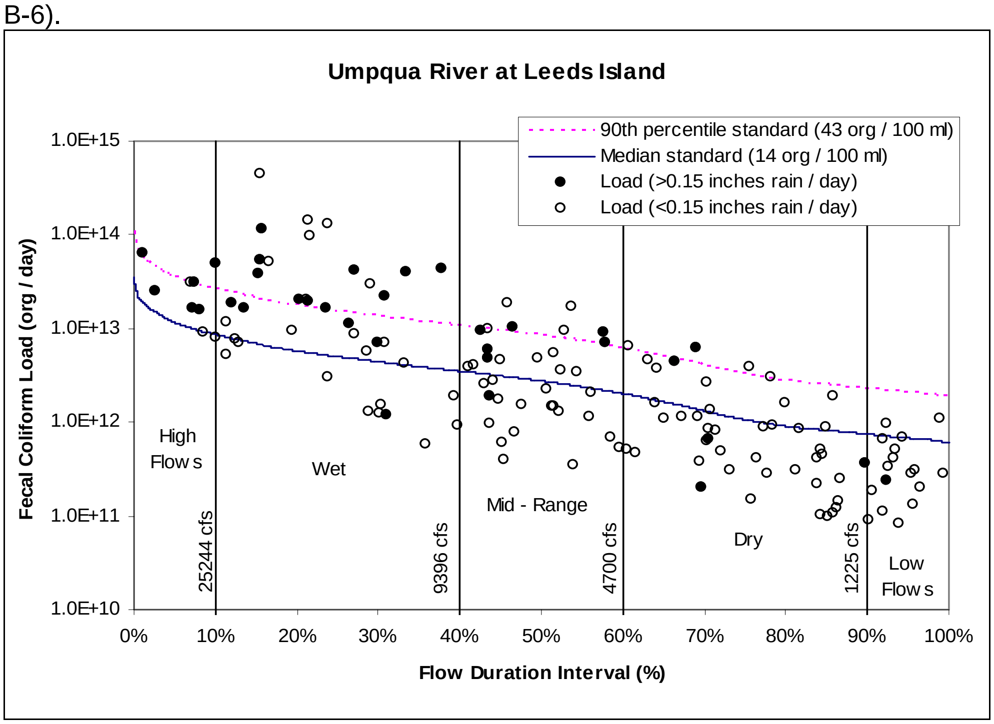

Figure B-6. Modified load duration curve for Umpqua River at Leeds Island (in estuary).

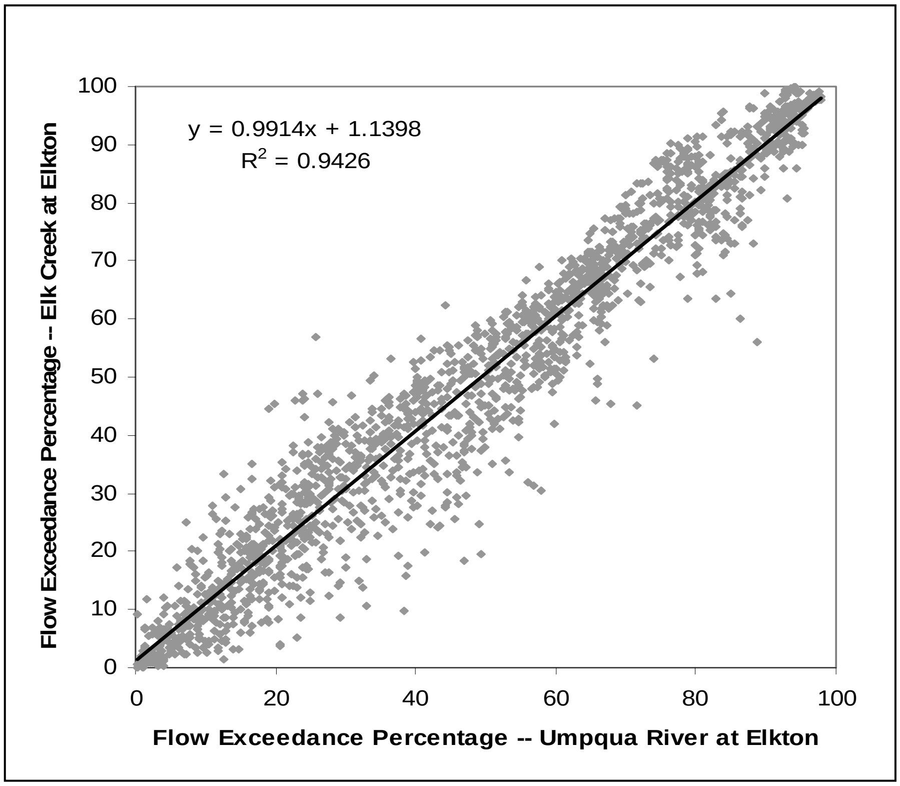

Figure B-7

Flow Calculations

The loading by flow regime of tributaries can be added together to predict loading downstream of their confluence. Summing the load based on the exceedence percentage assumes that the rivers and streams have similar hydrologic and hydraulic properties. For example, some streams in the Umpqua Basin are dominated by springs which deliver constant flow year round while other systems are dominated by rainfall / runoff or snowmelt. There is good agreement between the exceedence percentages for flow on Elk Creek at Elkton (293 square miles) and the Umpqua River at Elkton (3,683 square miles) (Figure B-7). Therefore it is appropriate to add these two loads together.

Flow-based Source Assessment

Fecal bacteria sources contribute to loading at during different flow regimes. Table B-5 can be used as a general guide for flow-based source assessment.

Table B-5 Generalized flow-based source assessment.

	Range of Flows				
Possible Sources	High Flow	Wet	Mid-Range	Dry	Low Flow
Direct Delivery (i.e., swimmers, wildlife, pets, livestock in-stream, illegal dumping)			M	H	H
Failing on-site wastewater systems		H	H	M	
Re-suspension	H	H	M		
Overland Flow	H	H	M		
WWTP overflow	H	M			

Note: Potential relative importance of source area to contribute loads under given hydrologic condition (H: High; M: Medium)

SECTION 3 – HYDROLOGY MODEL

Basin hydrology was modeled using the physically based Soil and Water Assessment Tool (SWAT), which was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) (Neitsch et. al. 2001). SWAT computes the land phase hydrology in multiple subbasins located within the watershed and then routes water through a river network (see Figure 1 for schematic). The hydrology model is used to estimate discharge in the portion of the Umpqua basin without flow gages. For a more complete discussion of the theoretical basis of SWAT, see Neitsch et. al. 2001.

Subbasin delineation was based on a 30-meter digital elevation model (DEM) and locations of monitoring stations. Within each Subbasin, an average of three hydrologic response units (HRUs) was determined by soil type (State Soil Geographic database) and land use distribution. The land use data is from a digital statewide zoning map and was generalized into four categories: agriculture, forest, high density residential / commercial and low density residential / commercial. Precipitation and air temperature were determined for each Subbasin based on the closest gage and the Subbasin's elevation distribution. Daily precipitation is based on ten rain gages within the Umpqua basin (Drain, Elkton, Gardiner, Glendale, Myrtle Creek, Oakland, Riddle, Roseburg, Toketee Falls, and Tiller), and minimum and maximum air temperatures based on six gages (Drain, Elkton, Gardiner, Riddle, Roseburg, Toketee Falls). Temperature was adjusted based on elevation using a lapse rate of –6 °C / km (default value). Daily precipitation was also adjusted based on elevation using a lapse rate of 10.5 mm / km calculated from PRISM (Parameter-elevation Regression on Independent Slopes Model) produced by Oregon State University, except for the Calapooya Watershed in which the lapse rate of 6 mm / km was used to match the observed water balance. Precipitation is classified as snow if air temperature is below freezing. Climatic stations at Roseburg and Elkton were used to estimate daily solar radiation, relative humidity, and wind speed.

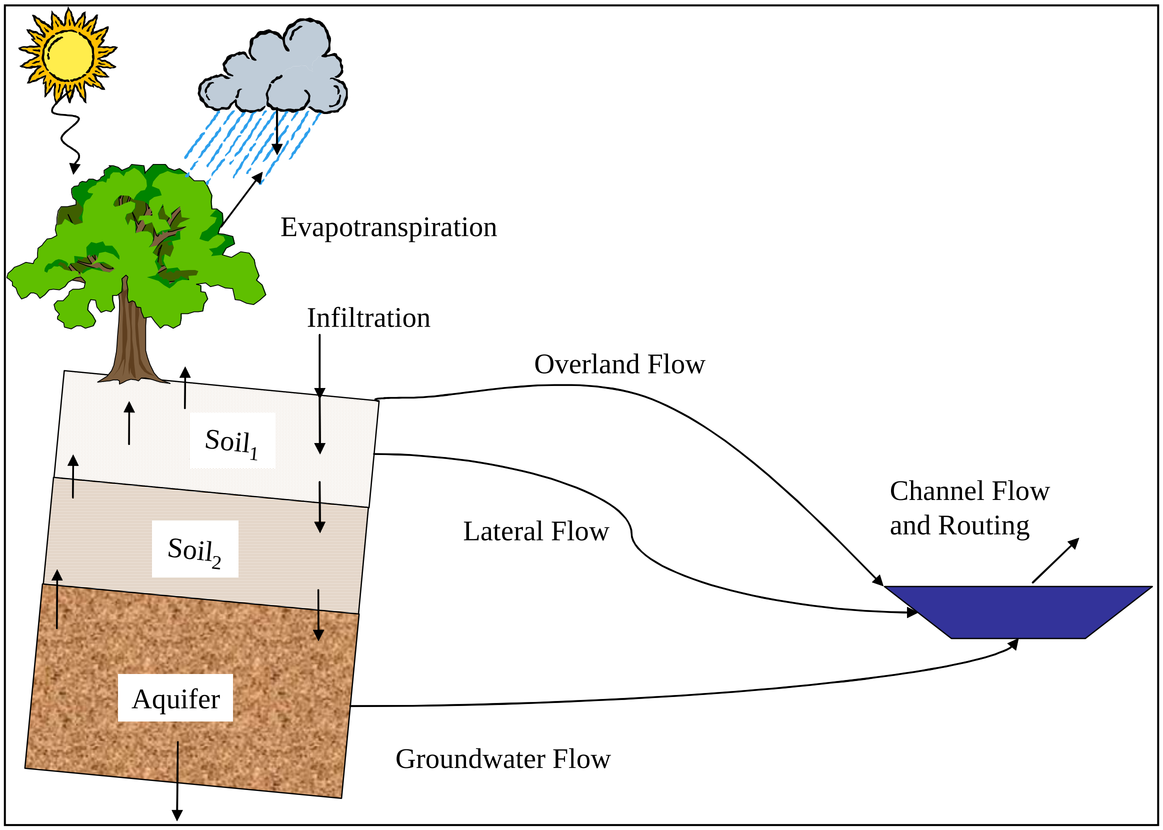

Figure 1. Hillslope hydrology schematic.

Water is transported out of the Subbasin by surface and subsurface flow to the river network, percolation to a deep regional aquifer, and evapotranspiration. Evapotranspiration is modeled using the Priestley-Taylor Method. The U.S Soil Conservation Service (SCS) curve number method is used to estimate runoff volume. This method incorporates soil's permeability, land use, and antecedent soil moisture. Time of concentration is used to estimate overland flow and tributary travel times. Percolation for each soil layer is calculated using a storage routing methodology. Lateral flow is represented in a kinematic storage model which simulates subsurface flow in the vertical direction and the direction of flow. Two aquifers are simulated in each subbasin: an unconfined aquifer which contributes to stream flow and a deep aquifer which transports water out of the watershed.

Water is routed through the river network using the Muskingum Routing Method that uses a combination of wedge and prism storage in each reach. Manning's equation, with an assumed trapezoidal channel and floodplain, is used to generate flow velocities (necessary to compute the Muskingum K value). The model also accounts for transmission losses into the substratum and evaporation from the river.

The non-physically based parameters were based on previous model results from the North Coast TMDL and are able to reproduce measured flows (Table 1 and Figure 2).

Table 1. Non-physically based model parameters.

Parameter	Value	Explanation
Bacteria Decay Rate	0.2	First Order Decay Rate, estimated from literature (EPA 2001), days-1
Precipitation Lapse Rate	10.5 4.0 (Calapooya)	Adjusts daily rainfall accumulations based elevations, mm / km
Deep aquifer percolation fraction	1.0	Controls volume of groundwater which percolates into the deep aquifer
Manning's n – Main Channel	0.035	Roughness coefficient
Manning's n – Tributaries	0.050	Roughness coefficient
Muskingum: coefficient 1	0.0	Governs the storage in reach at low flows
Muskingum: coefficient 2	2.0	Governs the storage in reach at high flows
Muskingum: X (weighting factor)	0.2	Governs the shape of the hydrograph

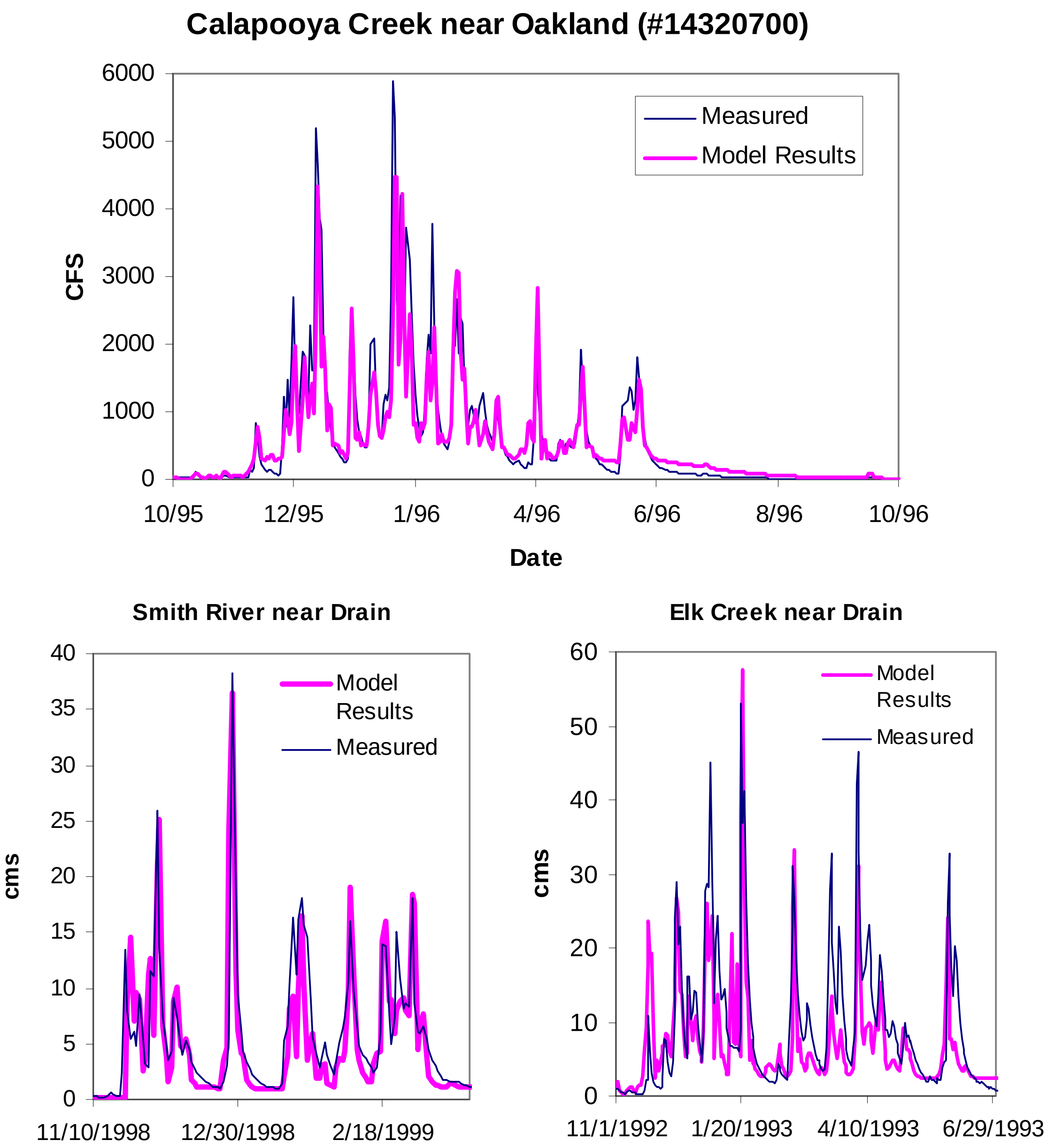

Figure 2. Examples of measured flow versus hydrology model results.