APPENDIX B: BACTERIAL MODELING

INTRODUCTION

The determination of bacterial allocations for non-point sources, and the relative contribution of point and nonpoint sources were made by modeling of bacterial concentrations in the Nehalem and Necanicum River Subbasins. This modeling was calibrated to bacterial concentration data collected during storm events and during dry-weather. A variety of landscape-scale data were included in the model to allow fine discrimination of bacterial accumulation given topography, landuse, soil type, and hydrology among other features. The sources of these data and their uses are described in the following sections of this appendix.

The Nehalem Subbasin was divided into upper and lower watersheds based on the finding that concentrations in the upper watershed generally met the water quality criteria, and there was little or no effect of upper watershed water quality on Nehalem Bay. The similarities in landscape and landuse between the Upper Nehalem and Clatskanie Subbasins allowed the adoption of Upper Nehalem nonpoint source allocations for the Clatskanie Subbasin.

BACTERIA MODEL

Overview

The bacteria model was used to estimate current loading conditions by land use and to determine load allocations necessary to meet water quality standards in the Nehalem Bay and Necanicum Estuary (**Figures 1 and 2**) where shellfish harvest is an existing use. Load allocations were also derived for the Clatskanie River, though this water body must meet a less stringent water quality standard designed to protect contact recreation. The bacteria model operates on a daily time step and has three basic components: watershed hydrology, watershed pollutant balance, and estuary pollutant balance. The hydrology governs the transport of bacteria within the watershed, delivering loads to the bay. Basin hydrology is 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). Bacteria enter the river network through storm generated overland flow, through constant direct input, and through wastewater treatment plants (WWTPs) (**Figure 2**). The bacteria loads are routed within the river network while experiencing first-order decay. The concentration of bacteria in the bay is determined from the upland loading and empirically determined, flow dependent dilution.

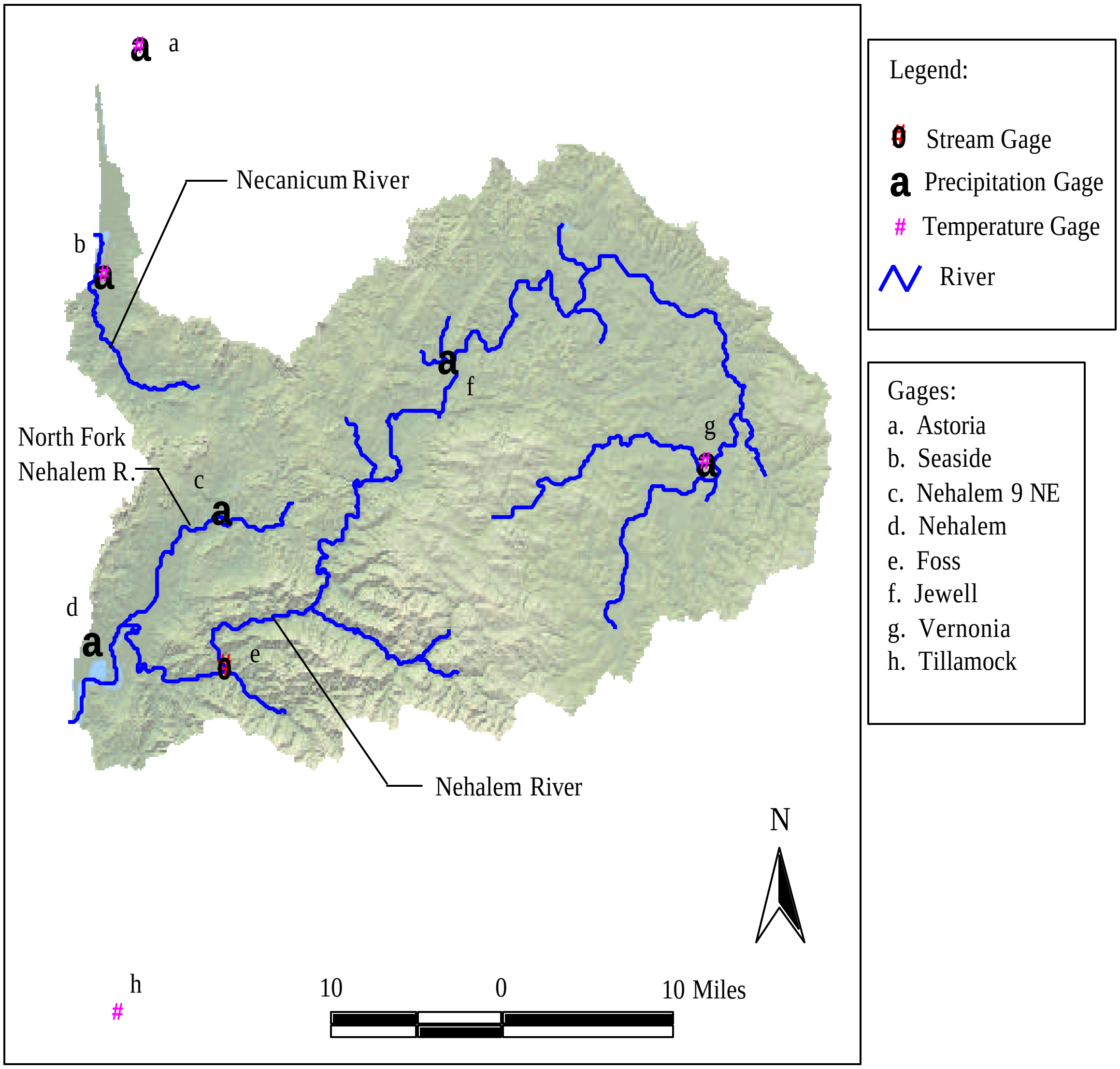

Figure 1. **Stream, precipitation, and temperature gages in and surrounding the Nehalem and Necanicum watersheds.**

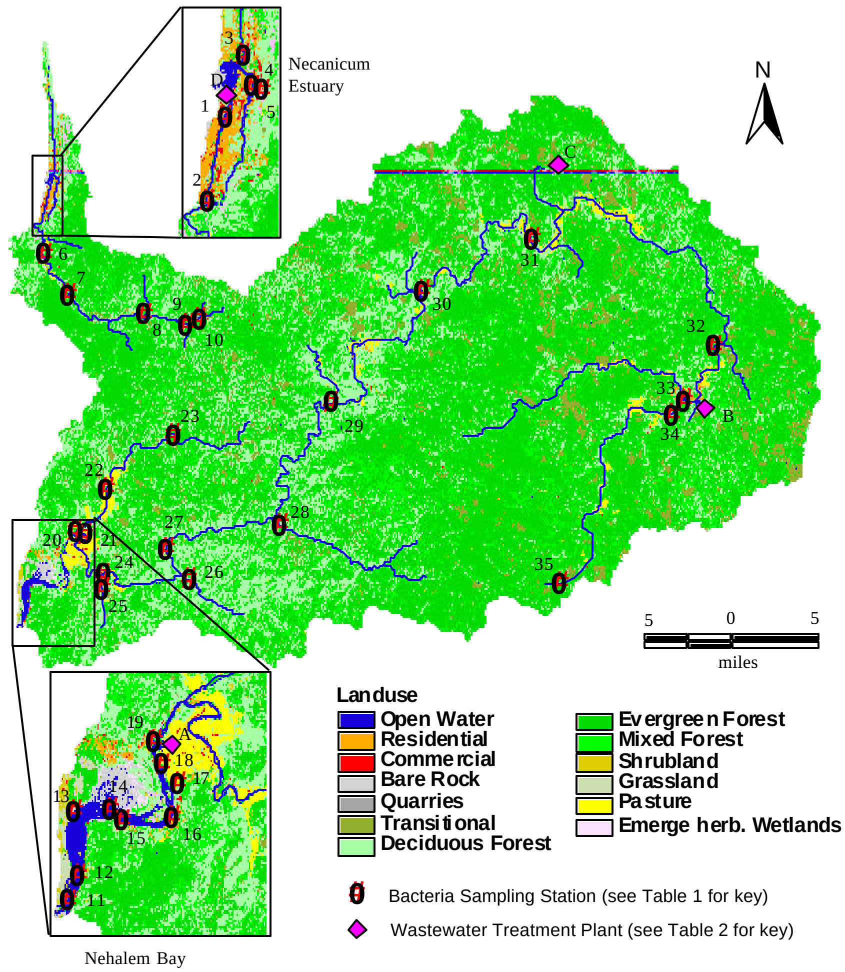

Figure 2. **Land use map with locations of bacteria monitoring sites and waste water treatment plants. See Table 1 and 2 for keys to station names.**

Bacteria concentrations are intrinsically variable. Analysis of 227 paired fecal coliform samples collected in Oregon during 1996 and 1997 reveals a standard error of 0.36 on the log scale (bacteria concentrations are log-normally distributed in the Nehalem watershed). When considering the median shellfish standard of 14 fecal coliform counts (cts) / 100 milliliter (ml), the concentrations between 6 and 32 cts/100 ml would fall within the standard error. Similarly, concentrations between 19 and 99 cts/100 ml fall within the standard error for the 90th percentile criterion concentration of 43 cts / 100 ml. It is important to consider this variability when analyzing individual samples and model results/predictions. Because of this variability, the model attempts to account for only the dominant loading, transport, and decay processes. The quantity of data available does not support the modeling of more complex processes, such as deposition and re-suspension of bacteria (Shere et. al. 1988), temperature dependent die-off rate (EPA 2001), or tidal fluctuations.

Despite the above limitations the bacteria model can account for processes occurring at the watershed scale and serves as a quantitative tool for determining spatially variable and land use dependent load allocations.

The bacterial TMDL is designed to protect two sensitive beneficial uses in two different landscape situations. Generally, samples were analyzed for *Escherichia coli* (*E. coli)* data at the freshwater sites and for Fecal Coliform at sites with measurable salinity because of the difference in indicator organisms in the recreational contact and shellfish growing water standards, respectively. Bacteria (*E. coli*) indicate impairment of the recreational use of rivers if concentrations exceed those determined through epidemiological studies to cause illness through body contact at a rate of 8 or more cases per 1000 swimmers. Bacterial (Fecal Coliform) concentrations in estuarine shellfish harvesting waters must be lower than those used for body contact, as shellfish filter large volumes of water and accumulate bacteria and the pathogens at concentrations higher than found in ambient water. The TMDL targets river concentrations that will limit the loading to the Bay and result in low concentrations in shellfish harvesting beds. Concentrations that meet the estuarine/shellfish criterion will also result in rivers meeting the recreational contact standard.

The indicator bacterium used by DEQ for assessing bacterial contamination for recreational waters changed in 1996 from fecal coliform bacteria to *E. coli*, the species associated with gut flora of warm-blooded vertebrates. In general, *E. coli* are a subset of Fecal Coliform bacteria. This change was made in part because *E. coli* is a more direct reflection of contamination from sources that also carry pathogens harmful to humans and is correlated more closely with human disease. Fecal coliform bacteria are still used in the standard as the indicator for protection of human health in assessing water quality in commercial shellfish harvesting areas. These areas and monitoring of water quality associated with them are under the jurisdiction of the Oregon Department of Agriculture (ODA). Since there are two standards that use two different indicators, DEQ still samples and analyzes water for both. This has resulted in a large data set of paired samples that allow statistical analysis and development of a mathematical relationship. Although the relationship is significant, bacterial concentration estimates in environmental samples are not very precise, as indicated by substantial variability among paired and duplicate samples. Concentrations of fecal coliform bacteria modeled to meet targets at the river mouths were converted to *E. coli* concentrations (per Cude 2001) for relevance to current and likely future monitoring activities

BASIN HYDROLOGY

SWAT computes the land phase hydrology in multiple subbasins located within the watershed and then routes water through a river network (Neitsch et. al. 2001). The hydrology model is especially important because it estimates the volume of storm generated overland flow by land use and the flow in the ungaged portions of the watersheds (i.e. North Fork of the Nehalem and the Necanicum River). The hydrology model was calibrated to the Nehalem River at Foss flow gage and then verified using various measurements throughout the basin (**Figure 1**). For a more complete discussion of the theoretical basis of SWAT, see Neitsch et. al. 2001.

The Nehalem and Necanicum watersheds were divided into 31 and 23 Subbasins, respectively. Subbasin delineation was based on a 30-meter digital elevation model (DEM) and locations of monitoring stations (**Figure 2 and Table 1**). Within each subbasin, an average of six hydrologic response units (HRUs) were determined by soil type (State Soil Geographic database) and land use distribution. The land use data is from National Land Cover Data at 30-meter resolution and was derived from 1992 Landsat Thematic Mapper images. Aerial photographs and zoning maps were also used to determine rural residential areas. The water balance is determined within each HRU using a hillslope model to account for precipitation, evapo-transpiration, infiltration, surface-runoff, soil moisture and subsurface flow.

Precipitation and air temperature is determined for each subbasin based on the closest gage and the subbasin's elevation distribution. Daily precipitation is based on six rain gauges within and nearby the watershed, and minimum and maximum air temperatures are based on four stations (**Figure 1**). Missing values were computed via linear regression based on available stations. Temperature was adjusted based on elevation using a lapse rate of –6 °C/km. 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. Precipitation is classified as snow if air temperature is below freezing. Climatic stations at Clatsop and Tillamook were used to estimate daily solar radiation, relative humidity, and wind speed.

Table 1. Monitoring sites in Nehalem and Necanicum River Subbasins.

Code (see Fig. 2)	LASAR ID	Name
1	11226	Necanicum River At 12Th Ave (Seaside)
2	23551	Necanicum River at U Street
3		Neacoxie Creek at "G" Street
4	24326	Neawanna Creek at Hwy 101 Bridge
5		Neawanna Creek at Stanley Lake fork
6	10521	Necanicum River At Riverside Lake Camp (Seaside)
7	23552	Necanicum River at Klootchie Creek Road
8	23555	North Fork Necanicum River at Hwy 26 (Necanicum RM15.2)
9	23558	Necanicum River at Hwy 53 (u/s of Bergsvik Creek)
10	23871	Necanicum River at Hwy 26 Bridge, RM 18.8
11	13298	Nehalem Bay At Jetty Fisheries
12	13297	Nehalem Bay At Brighton
13	13446	Nehalem Bay At Nehalem Bay St Park Boat Ramp
14	18886	Nehalem Bay At Green Marker #17
15	13296	Nehalem Bay At Paradise Cove Dock
16	13295	Nehalem Bay At Wheeler
17	24388	Gallagher Slough at Hwy 101 (Nehalem)
18	13640	Nehalem River At Hwy 101 (County Boat Ramp)
19	13639	Nehalem River At Nehalem City Dock (West Chan)
20	12866	Nehalem River North Fork At Mcdonald Road Bridge
21	24297	Nehalem River at RM 3.5
22	11428	North Fork Nehalem River At Alderdale
23	18802	North Fork Nehalem R At Highway 53
24	20440	Foley Creek @ Lommen Road
25	11856	Nehalem River At Foley Rd (Roy Creek Campground)
26	23292	Cook Creek at Mouth (Nehalem)
27	13368	Nehalem River At River Mile 15.0
28		Salmonberry River at Mouth
29	23509	Nehalem River d/s Humbug Creek at Lower Nehalem Rd.
30	23287	Nehalem River at Hwy 202 (Jewell)
31	23873	Nehalem River at Hwy 202 Bridge in Vesper
32	24300	Nehalem River at Hwy 47 Bridge in Pittsburg (RM 84.7)
33	11787	Rock Creek 200 Ft U/S Of Mouth
34	24299	Nehalem River at Hwy 47 Bridge u/s of Vernonia (RM 92.1)
35	23273	Nehalem River at Cochran Rd. Bridge 1393

Water is transported out of the subbasin by surface and subsurface flow to the river network, percolation to a deep regional aquifer, or 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 basin hydrology was modeled from September 1, 1995 until March 15, 2002. There are daily stream flow measurements during this period from the Nehalem River flow gage near Foss (USGS no.14301000) which accounts for 85% of the Nehalem watershed drainage area. The hydrology model was calibrated to the Foss Gage by varying water balance and routing coefficients to minimize the root mean square error (RMSE) between measured and modeled flows (**Figures 3 and 4 and Table 2**). The model reproduces the magnitude and timing of flows during wet and dry seasons. Comparison of measured flows and model output results in an R^2 value of 0.91.

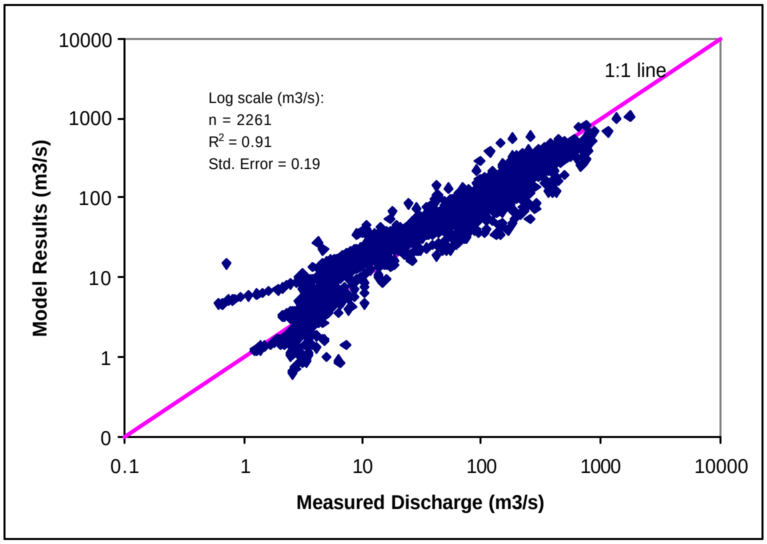

Figure 3.

Figure 4. **Sample year of measured and simulated stream flows at Nehalem River near Foss (calibration site).**

Figure 5.

Figure 6.

Figure 7.

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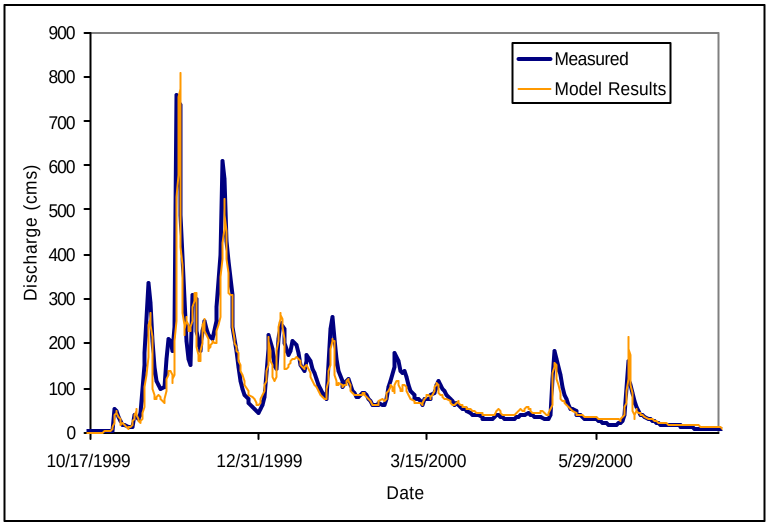


Figure 19.

Figure 20.

Figure 21.

Figure 22.

Figure 23. **Comparison of measured and simulated stream flow values at Nehalem River near Foss (calibration site) for September 1995 through November 2001.**

Model results were compared to 10 stream flow measurements collected in the Necanicum River at Klootchie Creek Road during winter 2001 (**Figure 5**), 21 measurements throughout the Nehalem and Necanicum watersheds during early August, and daily measurements from the USGS Gage near Vernonia (Gage No. 14299800) between September 29 and November 30, 2001 (**Figure 6**). The model predicted flows at sites other than the calibration station with an R^2 statistic of 0.84 and a standard error of 0.36 log (m^3/s). Based on this comparison, the hydrology model can be used to predict daily flows at other times and in other portions of the Nehalem watershed and in surrounding basins, notably the Necanicum River and the North Fork of the Nehalem River.

Table 2. SWAT bacteria modeling input parameter values

Parameter	Value	Explanation
Precipitation Lapse Rate	10.5 mm/km	Adjusts daily rainfall accumulations based elevations
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 24. **Measured point values and continuous predicted values of flow at Necanicum River .**

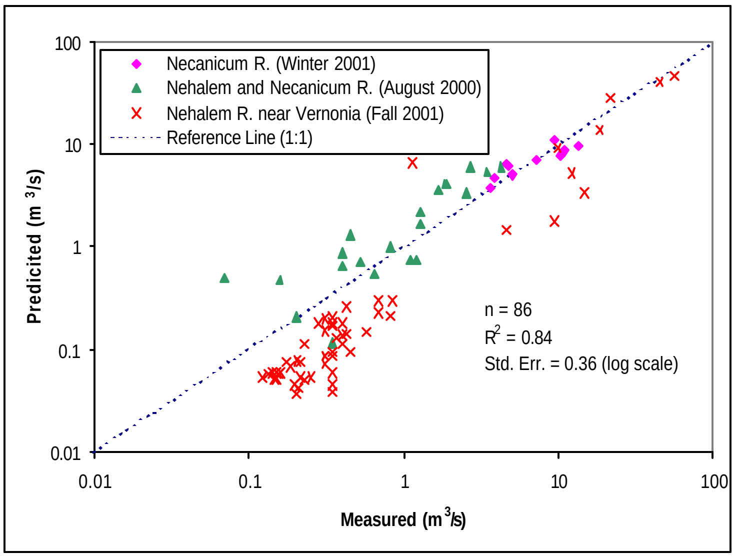
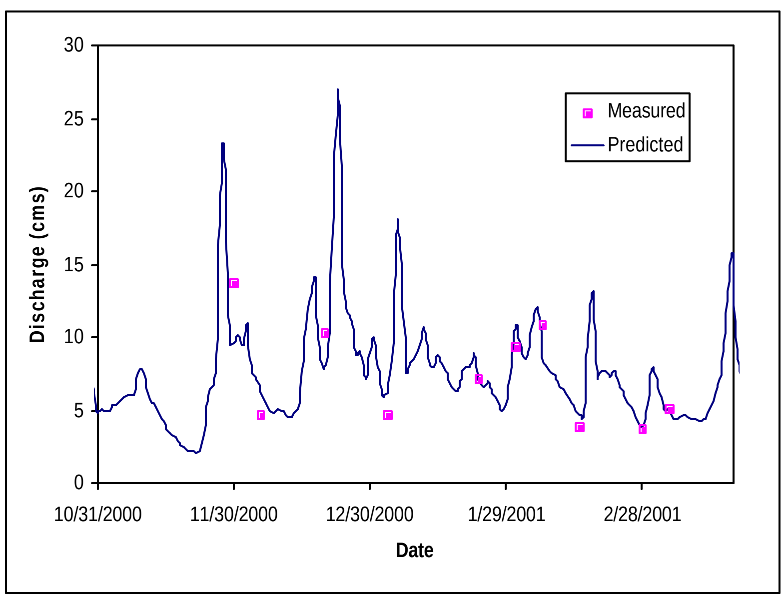


Figure 25. **Measured versus predicted flow values.**



BACTERIA LOADING

Bacteria loading to river network was represented in three ways: permitted point sources, non-point source direct loading, and non-point source storm loading. Bacteria loading from permitted point sources was estimated from flow and *E. coli* measurements reported by the point sources during 2001 (**Figure 2 and Tables 3 and 4**).

Table 3. Wastewater treatment plants

Code (see Fig. 2)	Facility ID	Name
A	61787/A	Nehalem Bay Wastewater Agency
B	92773/A	City of Vernonia
C	29850/A	Fishhawk Lake Recreation Club, Inc.
D	79929/A	City of Seaside

Table 4. Reported Daily Wasteloads by season for Wastewater Treatment Plants (WWTP) and Confined Animal Feeding Operations (CAFO). CAFO loads are limited by permit requirements.

	Nehalem WWTP	Vernonia WWTP	Fishhawk Lake WWTP	Seaside WWTP	Clatskanie WWTP
Facility ID	61787/A	92773/A	29850/A	79929/A	
Jan - Mar	$1.43x10^{9}$	$6.05\ x10^{7}$	$2.59\ x10^{7}$	$6.77\ x10^{8}$	$5.45\ x10^{7}$
Apr - June	$1.96\ x10^{8}$	$7.20\ x10^{6}$	$1.01\ x10^{7}$	$4.44\ x10^{8}$	$3.19\ x10^{7}$
July - Sept	$1.41\ x10^{8}$	No Discharge	$5.41\ x10^{7}$	$2.88\ x10^{8}$	$2.66\ x10^{7}$
Oct – Dec.	$1.73\ x10^{8}$	$1.21\ x10^{9}$	$7.19\ x10^{8}$	$5.74\ x10^{8}$	$6.23\ x10^{7}$

WWTP = wastewater treatment plant
*No permitted discharge into the Nehalem River from June 15 until October 25, 2001.

Direct loading from non-point sources is a constant *E. coli* load delivered to the river each day. This type of loading represents inputs such as septic tanks, wild and domestic animal waste deposited into streams, and misapplication of fertilizer. Although these direct sources were not observed, the impact of direct loading on the Nehalem and Necanicum Rivers was captured during a three day, intense sampling event during September 18 – 20, 2000. There was no rain recorded in the seven days prior to the sampling event. Trace amounts of rain (0.01 inches) were recorded at the Seaside rain gage during the sampling event. Flows at the Nehalem River near Foss dropped from 2.2 to 1.9 cubic meters per second (cms) during this period. Six to eight samples were used to determine median and 90th percentile concentrations at 30 different monitoring sites (Figure 7). The greatest *E. coli* concentrations were measured at the North Fork of the Nehalem River at Aldervale with a log mean of 243 cts / 100 ml, a 90th percentile of 398 cts / 100 ml, and a maximum of 488 cts / 100 ml. These concentrations exceed the recreational contact standard. This site is located in a river reach in which the valley floor is dominated by pasture and CAFOs. There is also a notable decrease in concentration between the upper and lower Nehalem watershed. Median E. coli concentrations between Nehalem River downstream of Humbug Creek and Nehalem River at River Mile 15 (Figure 2, stations 29 and 27, respectively) decrease from 51 to 14 cts / 100 ml and the 90th percentile from 71 to 21 cts / 100 ml.

Lastly, nonpoint source storm loading is delivered to the river network by assigning a constant *E. coli* concentration to storm generated overland flow based on land use type. Storm runoff concentrations are used as a surrogate measure for load. DEQ collected daily or twice-daily bacteria samples in the Nehalem Watershed and Bay between October 29 and November 1, 2001 during a storm event. On October 31, 26.9 mm (1.06 inches) of rainfall was recorded at the Nehalem 9 NE gage and was followed by an increase in the Nehalem River flow from 13 to 41 cms (Figure 1 and 8). The exceedence probability of 26.9 mm of rain is 0.1, meaning that 10% of the days exceed this rainfall accumulation. The exceedence probability of 41 cms is 0.45, so approximately 45% of flows would exceed the peak flow during this event. These statistics show that this storm event and flow were representative of this basin.

Spatial variability in rainfall accumulation is also apparent in this storm between the Nehalem 9 NE and Vernonia Gage (Figure 8). *E. coli* concentrations increased dramatically during the storm event with the maximum measured being 12,033 cts / 100 ml at Gallagher Slough (Figure 9 and 10). A large portion (greater the 75%) of the land that drains through Gallagher Slough is pasture and CAFOs. Four additional monitoring sites had concentrations above 406 cts/100 ml – the maximum concentration allowed for the recreational contact standard (Figure 10). These sites are all located adjacent to pasture land.

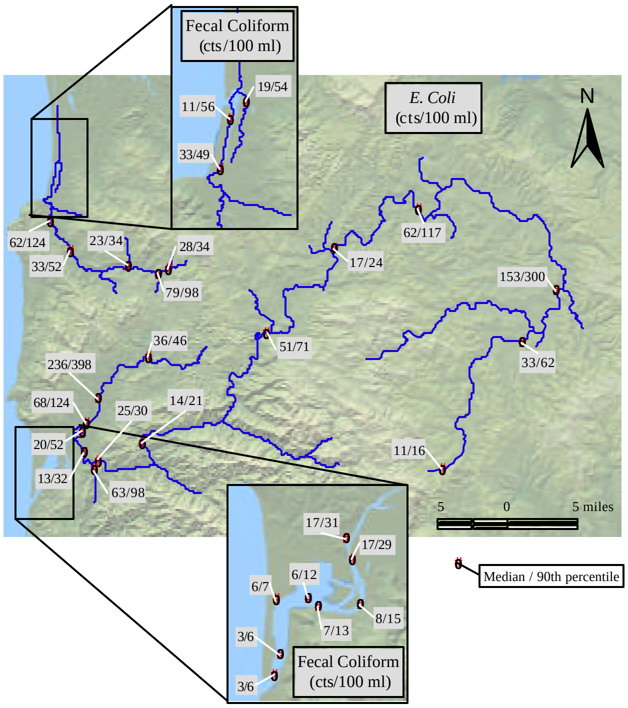


Figure 26. **Results from dry weather sampling event, September 2000. Median and 90th percentile values are reported for each monitoring site. In the estuaries, fecal coliform results are presented while for the upland sites, *E. coli* results are reported. Six to eight samples were analyzed from each site.**

A load duration curve summarizes loading data and flow conditions by plotting the log of bacterial loading rate (in counts/day) against the exceedance probability of flow rate. High exceedance probabilities correspond to low flow rates and vice-versa. Loads greater than the critical value (based on the water quality numeric criteria) indicate point sources at high exceedence probabilities (low flows) and non point sources at low exceedence probabilities (high flows). The load duration curve for the North Fork of the Nehalem River at McDonald Road Bridge was constructed using the output from the hydrology model (**Figure 11**). Exceedences of the recreational contact maximum standard of 406 cts/100 ml occur along the continuum of flow regimes. This indicates that both direct and indirect sources of bacteria are responsible for violations of water quality standards. There are no treatment plants in this river, so direct discharges would be failing septic systems, misapplied manure, and livestock in creeks.

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 bacteria model included the following first order decay equation (EPA, 2001):

$$N_b = N_a \exp\left(-K \cdot t_{a,b}\right)$$

where N_b is number of bacteria at point *b* which is downstream of point *a*, *K* is the first of decay rate (days^{-1}), $t_{a,b}$ is the travel time between points *a* and *b*. The concentration is then the number of bacteria per volume water within a reach segment. Daily overland flow volume, river discharge, and travel times were generated from the hydrology model. Temperature dependent decay rate did not improve the quality of the model results based on the RMSE. Simple first-order decay was retained in the model.

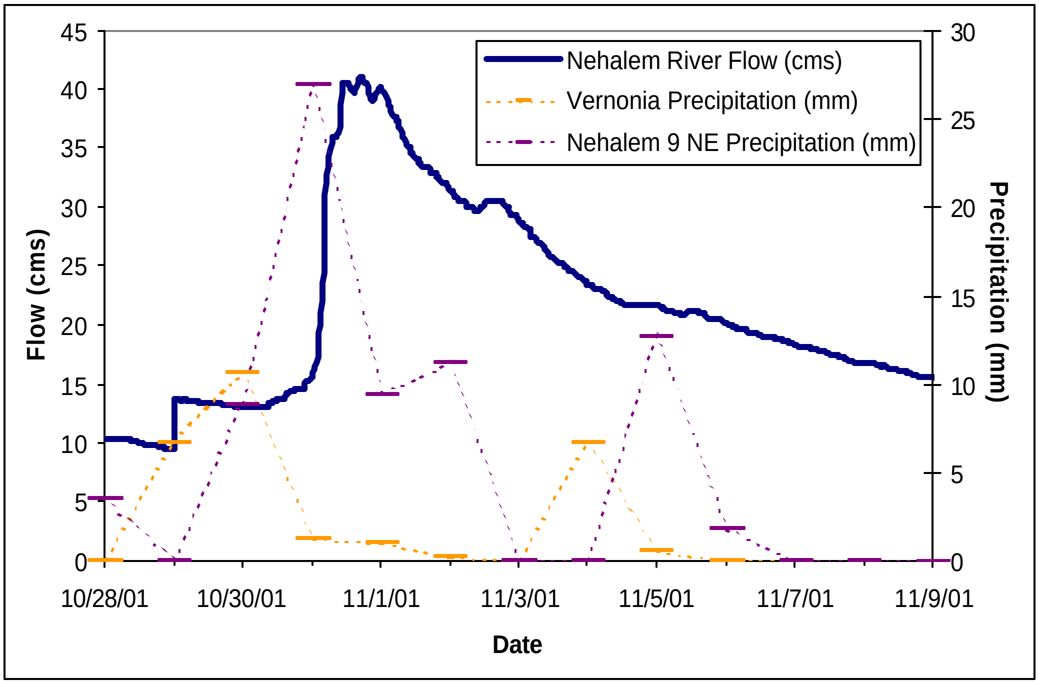


Figure 27. **Hydrograph of the Nehalem River at Foss with daily accumulations of precipitation during the intensive storm sampling October 2001.**

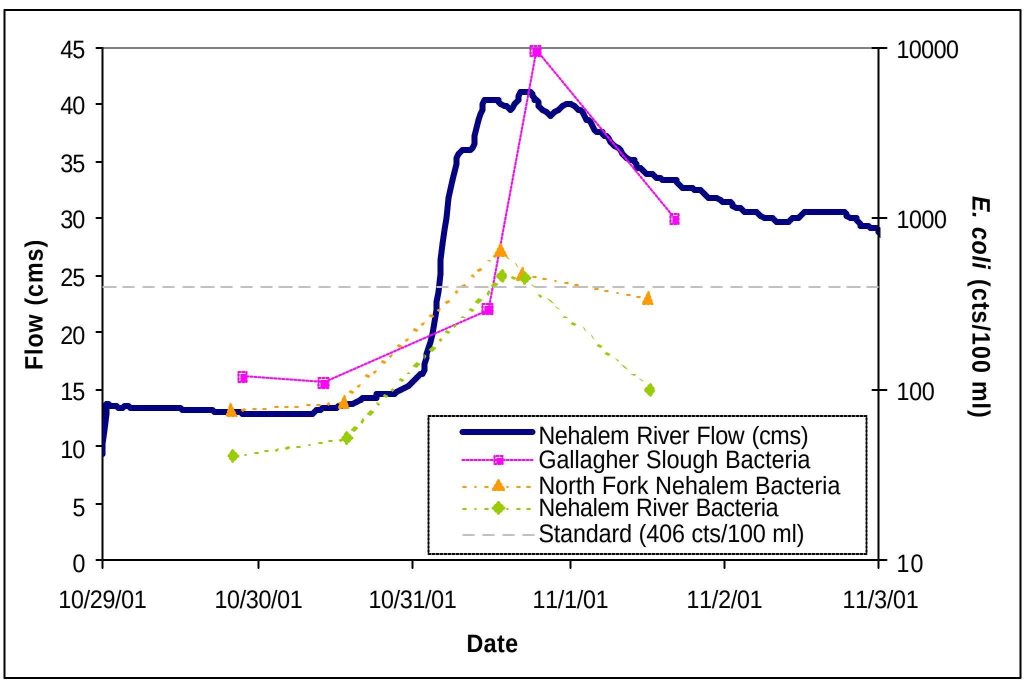


Figure 28. **Hydrograph of the Nehalem River at Foss with bacteria concentrations.**

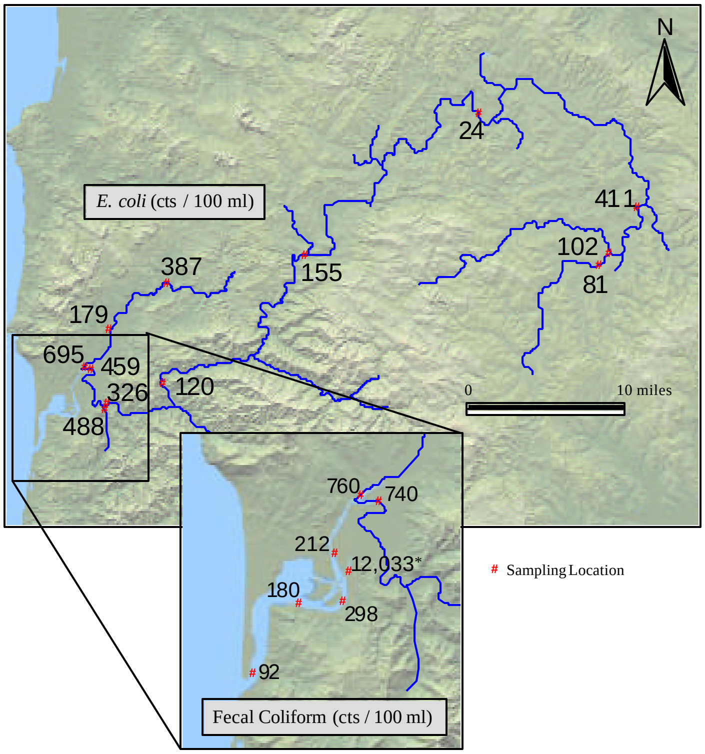


Figure 29. Peak *E. coli* and fecal coliform concentrations during storm sampling, October 2001.

Present Conditions

Present *E. coli* loading conditions were determined either from previous bacteria studies or by determining the loads which result in the least amount of error between model results and measured values (Tables 5 through 8). In the Nehalem watershed, the storm runoff concentration from developed areas and direct loading from septic tanks were estimated using previous studies. *E. coli* concentration in runoff from urban / residential areas of 1400 cts / 100 ml was estimated from measured concentrations from similar land uses in the Nestucca watershed (DEQ, 2002). The septic load was estimated by the following:

Septic Load = # of households ´ failure load ´ failure rate

The number of households not serviced by a WWTP was estimated by aerial photographs, the failure load equals 1.5×10^8 counts / failing unit / day and the failure rate was estimated at 5% (Swann 2001 and DEQ 2002).

The remaining loads to the Nehalem watershed and the first order decay rate were determined through the minimizing of the RMSE. In the Nehalem watershed, 520 *E. coli* measurements from 13 sites collected between September 1997 until November 2001 were used to estimate the loading from pastures, CAFOs, and forest / non-developed land (**Tables 5 and 6**). Data was collected by the Lower Nehalem Watershed Council, DEQ and Department of Agriculture (ODA). Measurements from Cook Creek and Salmonberry Creek provided for calibration of the forest / non-developed land use sources of *E. coli*. The first order decay rate was determined to be 0.8 $days^{-1}$ by minimizing RMSE in the Nehalem watershed.

Table 5. Nehalem watershed storm runoff concentrations

Source – Storm Runoff	Present *E. coli* (cts / 100 ml)	Reduced *E. Coli*. (cts / 100 ml)	Reduction (%)
CAFOs	10,000	0	100
Low Pasture	10,000	500	95
Upper Pasture	10,000	4500	55
Low City	1400	500	65
Upper City	1400	630	55
Non Anthropogenic	60	60	0

Table 6. Nehalem watershed direct loads

	Units	Current	Allocation	Reduction (%)
CAFO	cts / animal / day	6.0E+7	0	100
Septic	cts / units / day	7.6E+5	0	100
Upper Pasture	cts / km^2 / day	4.5E+9	2.0E+9	56
Lower Pasture	cts / km^2 / day	4.5E+9	2.2E+8	95
Non Anthropogenic	cts / km^2 / day	8.9E+7	8.9E+7	0

The Waste Load Allocations to CAFOs includes the surrounding pasturelands associated with the operation. Surrounding pasturelands were estimated by assuming that the 0.5 acres was associated with each adult animal. Therefore, in the Nehalem Subbasin an estimated 650 acres are associated with CAFOs and in the Necancicum subbasin 440 acres. For analyses and allocation purposes, pastureland associated with CAFOs is differentiated from pastureland not associated with CAFOs.

All loading in the Necanicum watershed was determined through minimizing error when comparing 163 *E. coli* measurements from 10 sites collected between March 1996 and February 2002 (**Tables 7 and 8**). Data was collected by DEQ and ODA. Freshwater equivalent concentrations were computed when measurable salinity was present by assuming dilution with sea water containing no bacteria. Due to the greater precentage of developed and rural-residential land uses in the Necanicum watershed (11% compared to <1% in the Nehalem watershed), direct loading was calculated differently in the Necanicum watershed. Direct loading was determined for developed and rural residential land uses, as opposed to estimating the number of septic tanks. The same first order decay rate was used on the Necanicum as the Nehalem watershed.

Table 7. Necanicum watershed storm runoff concentrations

Source – Storm Runoff	Present *E. coli* (cts / 100 ml)	Reduced *E. coli* (cts / 100 ml)	Reduction (%)
Pasture	2500	304	88
Developed	420	96	77
Rural Residential	175	72	59
Non Anthropogenic	60	60	0

Table 8. Necanicum watershed direct loads

	Units	Current	Allocation	Reduction (%)
Pasture	cts / km^2 / day	6.1E+7	4.2E+7	31
Developed	cts / km^2 / day	3.0E+9	9.2E+8	69
Rural Residential	cts / km^2 / day	1.1E+10	3.3E+9	70
Non Anthropogenic	cts / km^2 / day	3.4E+7	3.4E+7	0

The model is able to capture the general trend of *E. coli* concentrations in the Nehalem and Necanicum watershed under a variety of flow conditions with an R^2 statistic of 0.32 and 0.33, respectively, and a standard error of 0.51 log (**Figure 12**). Based on paired sample analysis, the intrinsic standard error of *E. coli* is 0.30 log. The model is able to reproduce median and 90th percentile concentrations at 13 different stations in the Nehalem watershed with an R^2 of 0.81 and a standard error of 0.21 log (**Figure 13**).

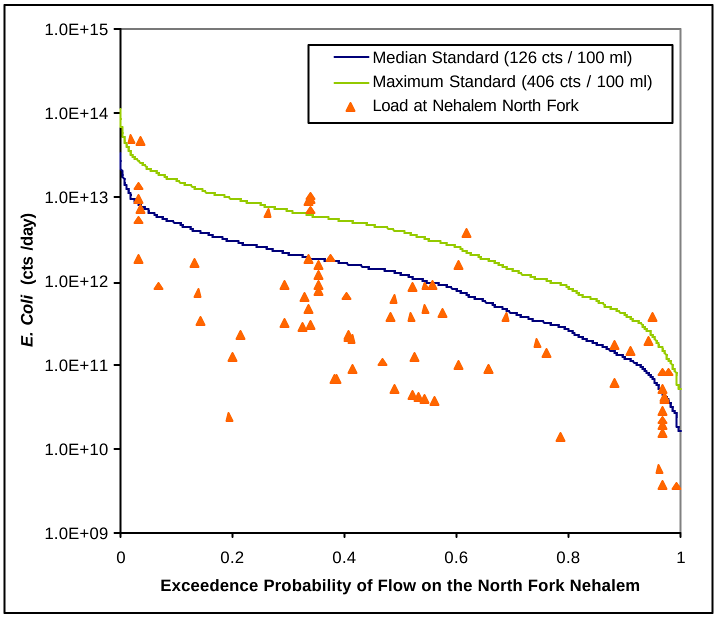


Figure 30. **Load duration curve showing the distribution of E. coli loads with the exceedence probability of flow on the North Fork of the Nehalem. A high exceedance probability corresponds to a low flow rate.**

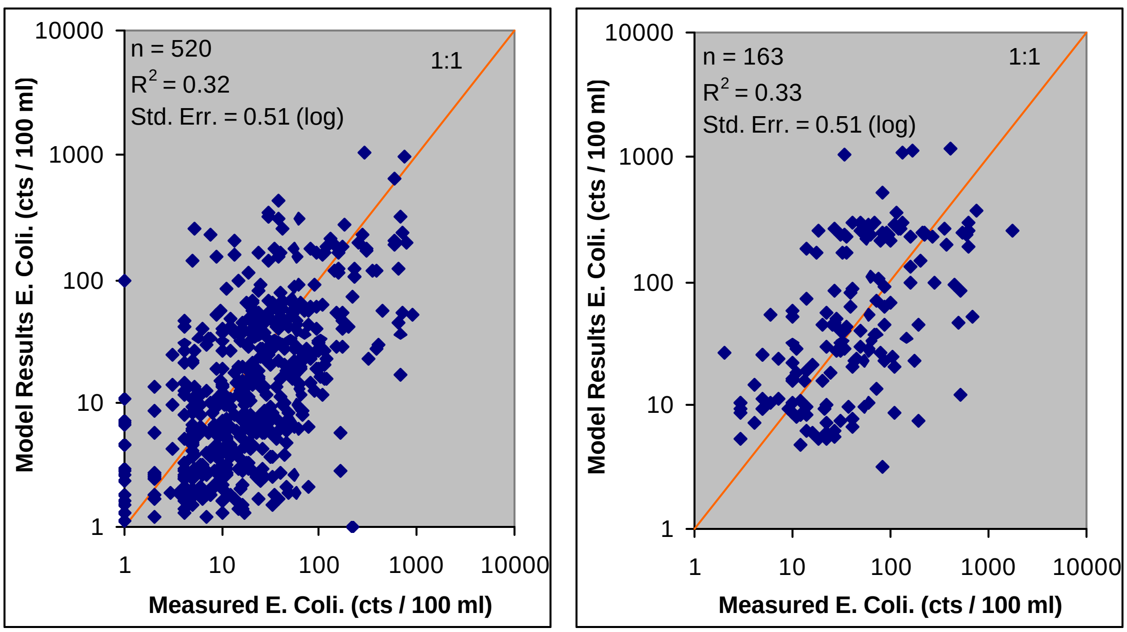


Figure 31. **Measured E.Coli. concentrations versus model results from the upland bacteria loading model in the Nehalem (left) and Necanicum (right) watersheds (1996 – 2002).**

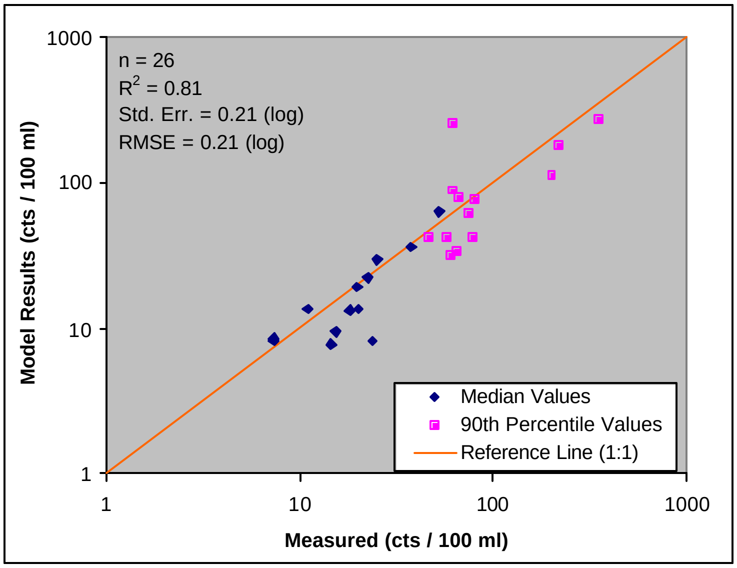


Figure 32. **Median and 90th percentile values of E. Coli. concentrations for individual sampling locations versus model results in the Nehalem watershed.**

ESTUARY MODEL

During the dry-weather September 2000 intensive sampling event, fecal coliform concentrations tended to increase with distance from the mouth of the Bay (**Figure 14**). The fresh water equivalent concentration was computed using salinity as an indicator of fresh and seawater mixing with seawater contributing no bacteria. There does not appear to be a longitudinal trend of the fresh water equivalent concentration (**Figure 15**). Likely, natural bacteria loading from marine mammals and wild fowl is balanced by increased bacteria sedimentation and greater decay due to increased residence time, salinity, and exposure to sunlight (EPA 2001). Salinity provides a conservative tracer to estimate the amount of dilution. A relationship between salinity and flow at the Foss Gage was developed for the eight sampling sites in the Nehalem Bay (see **Figure 16** for example at Wheeler). For example at Wheeler, salinity concentrations can be estimated using the following:

$$S_x = -12.14 \cdot \log\left(Q_{foss}\right) + 42.92$$
$$0 \le S_x \le 35$$

where S_x is the salinity concentration (part per thousand [ppt]) at location x, Q_{foss} is the flow at the Foss Gage (cfs). The average R^2 value for the salinity – flow regression was 0.63 and average standard error for the regression was 3.8 ppt.

The watershed bacteria model predicts the load of *E. coli*, however the shellfish standard uses fecal coliform as an indicator organism. DEQ has developed the following relationship between *E. coli* and fecal coliform concentrations based on paired samples collected throughout the state (Cude 2001):

$$E.\ coli = 0.530855 * (fecal\ coliform)^{1.05652}$$

Using this relationship the watershed bacteria model can predict the concentration of fecal coliform in the bay if there was no dilution with seawater. The actual concentration at different sites in the bay can be estimated using the following:

$$C_x = C_f\left(1 - \frac{S_x}{S_s}\right) + C_s\left(\frac{S_x}{S_s}\right)$$

where C_x is the fecal coliform concentration (cts / 100 ml) at location x, C_f is the concentration of fecal coliform predicted by the bacteria loading model (no dilution), S_s is the estimated salinity concentration of the ocean (35 ppt) and C_s is the fecal coliform concentration of the ocean. The model provided the best results based on RMSE when the ocean water contributed no fecal coliform.

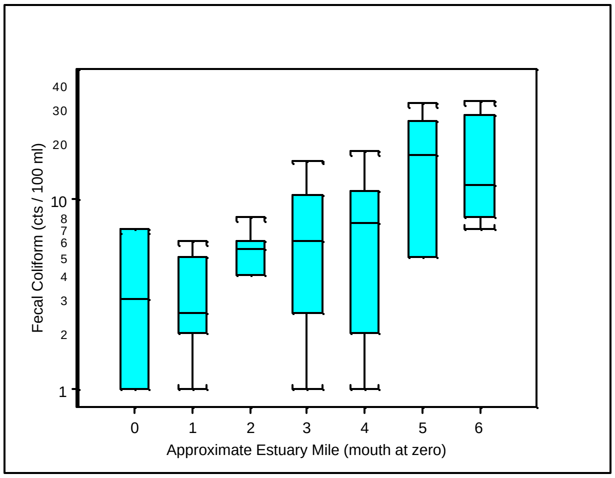


Figure 33. **Box and whisker plot of concentrations of fecal coliform in Nehalem Bay during the dry weather (September 2000) sampling event (at least six samples per location).**

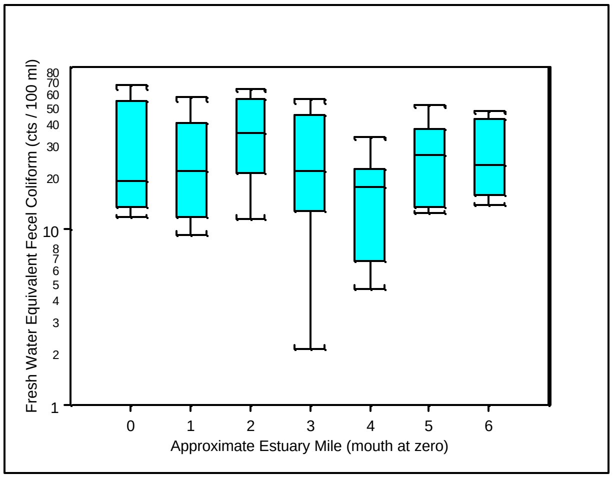


Figure 34. **Box and whisker plot of fresh water equivalent of fecal coliform in Nehalem Bay during the dry weather (September 2000) sampling event (same data as Figure 14). Fresh water equivalent was computed from salinity measurements and assuming that sea water diluted bacteria concentrations.**

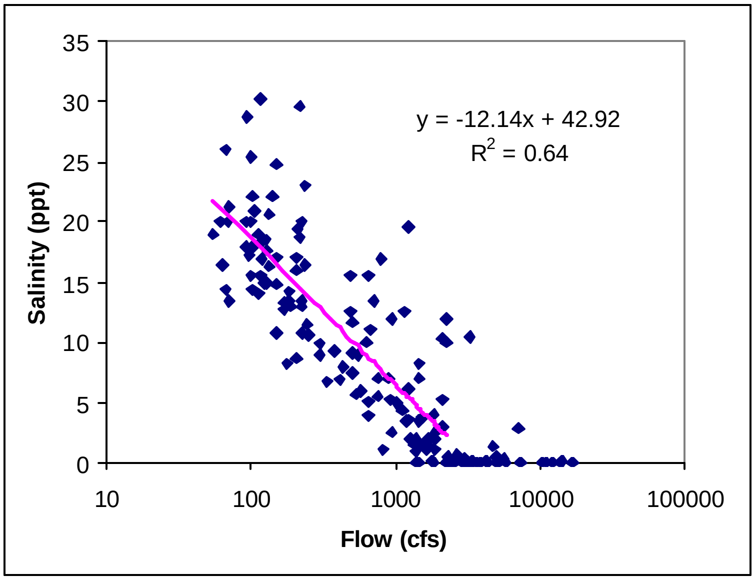


Figure 35. **Linear regression of Salinity versus flow at Wheeler in the Nehalem Bay.**

The model effectively predicted the general trend of fecal coliform concentrations with a standard error of 0.56 log as compared to a standard error of 0.51 log for the *E. coli* river loading and 0.36 log for intrinsic variation of fecal coliform (**Figure 17**). The model performs with an R^2 of 0.98 when comparing median and 90th percentile values of the monitoring sites in the bay (**Figure 18**). Model results of fecal coliform concentrations in the bay follow the same seasonal pattern as measured results at Wheeler with the highest concentrations occurring during the fall due to the combination of greater flows and high concentrations (**Table 9**). Based on a moving 90-day window, under current loading conditions, the model predicts the greatest violations in water quality standards at Nehalem Bay at Wheeler occurred during the late fall and early winter (**Figure 19**). Water quality standards were generally met during the later summer.

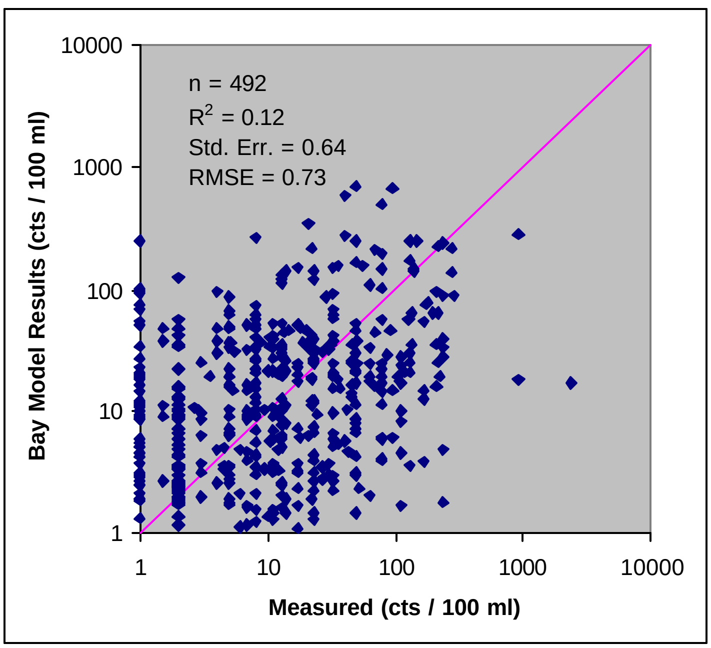


Figure 36. **Measured fecal coliform concentrations versus model results in Nehalem Bay.**

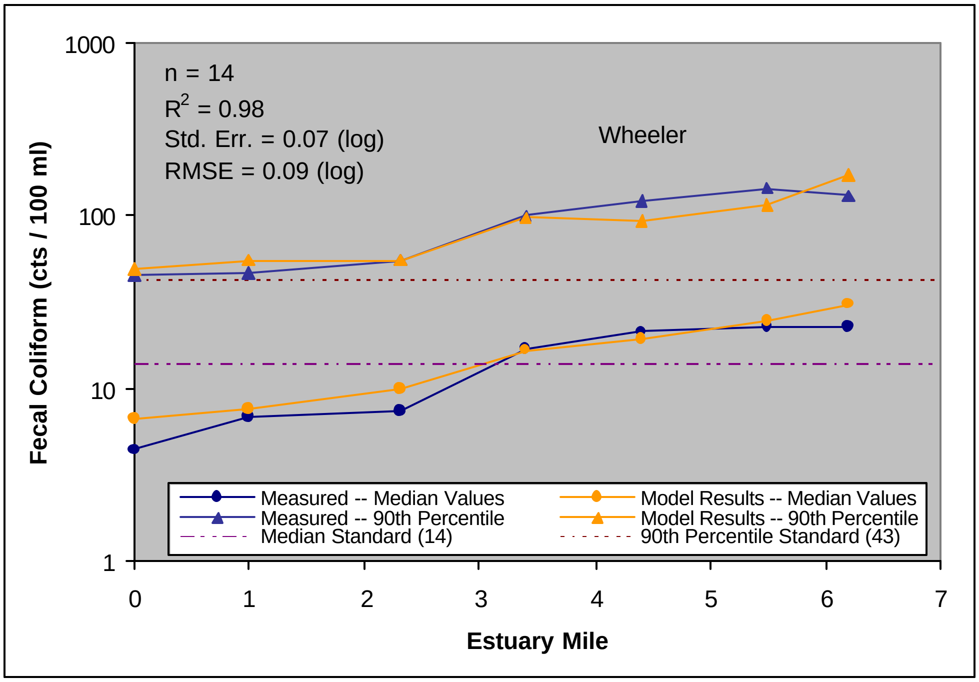


Figure 37. **Comparison of median and 90th percentile measurements and model results for the Nehalem Bay. Nehalem Bay at Wheeler is 4.4 miles from the Pacific Ocean.**

The Necanicum estuary was modeled similarly. Fecal coliform concentrations were estimated by the following empirically derived flow – salinity relationship at 12th Street in Seaside (**Figure 19**).

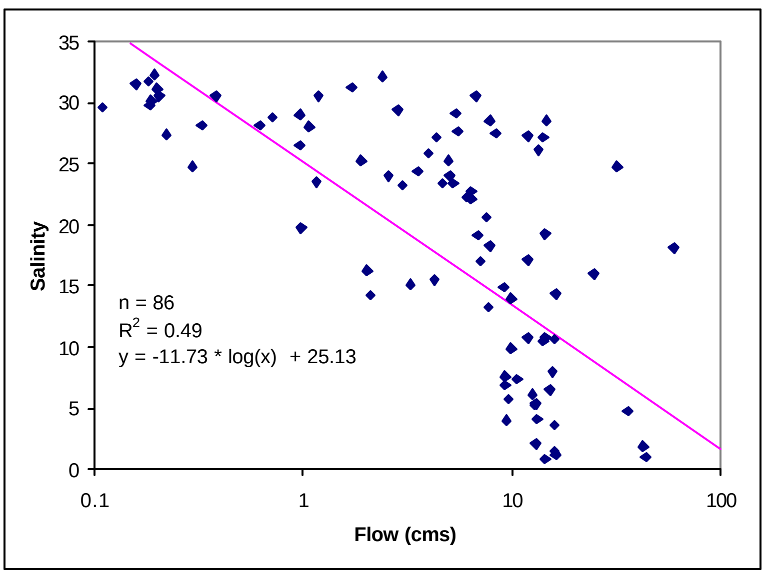


Figure 38. **Salinity as a function of flow in the Necanicum River at 12th St. in Seaside.**

This relationship allowed estimation of dilution through the regression equation:

$$S_x = -11.73 \cdot \log(Q) + 25.13$$
$$0 \leq S_x \leq 35$$

where flow is estimated at 12th Street in Seaside from the hydrology model. The relationship was based on 86 measurements and had an R^2 of 0.49. The flow—salinity relationship was used for the entire estuary. There were no sites in the estuary below the WWTP, the confluence with Neacoxie Creek, or the confluence with Neawanna Creek. The estuary model, though, does account for the loading from these sources.

Table 9. Seasonal variation of measured and modeled fecal coliform (cts / 100 ml) at Wheeler in Nehalem Bay.

	Median		90th Percentile	
Time Period	***Measured***	Model Results	Measured	Model Results
Jan – Mar	15	27	76	97
Apr – June	14	7	80	69
July – Sept	17	14	76	45
Oct – Dec	49	50	150	181

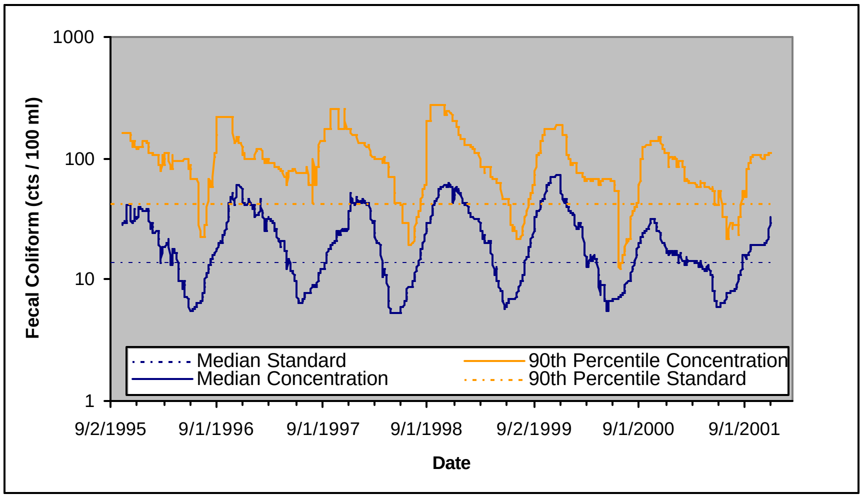


Figure 39. Current median and 90th percentile values based on model results. Statistics are based on a 90-day moving window.

Nehalem Watershed Allocations

The bacteria model was used as a source assessment to estimate bacteria load in the bay by land use and position in the watershed. Due to the decay rate associated with bacteria, the upper watershed has less of an impact on bacteria loading on a per acre land use basis. The upper watershed is defined as the watershed above the confluence of the Nehalem River and the Salmonberry River and includes the towns of Vinemaple, Mist, and Vernonia. The lower watershed includes areas which drain into the Nehalem River below the Salmonberry confluence, the entire North Fork of the Nehalem River, and the Nehalem Bay.

Wheeler is the approximate upstream extent of shellfish harvesting (Deb Cannon, Personal communication), though commercial shellfish harvesting is classified as prohibited north of a line drawn between Nehalem Bay State Park and Fishery Point. Harvesting in other areas is for recreational harvesters only. Median and 90th percentile values of fecal coliform concentrations both decrease in the downstream direction in the bay. Therefore if concentrations at Wheeler are meeting water quality standards, it is assumed that locations downstream of Wheeler are also meeting water quality standards. No significant sources of fecal coliform were identified downstream of Wheeler.

The maximum load for each land use was determined by reducing storm runoff concentrations and direct loading until the shellfish standard was not exceeded for the model period (September 1995 until March 2002) (**Figure 20**). The median fecal coliform standard of 14 cts / 100 ml and 90th percentile standard of 43 cts / 100 ml were computed using a 90-day moving window. A 90-day period captures the seasonal variation but filters daily concentrations which the model is not able to reliably predict.

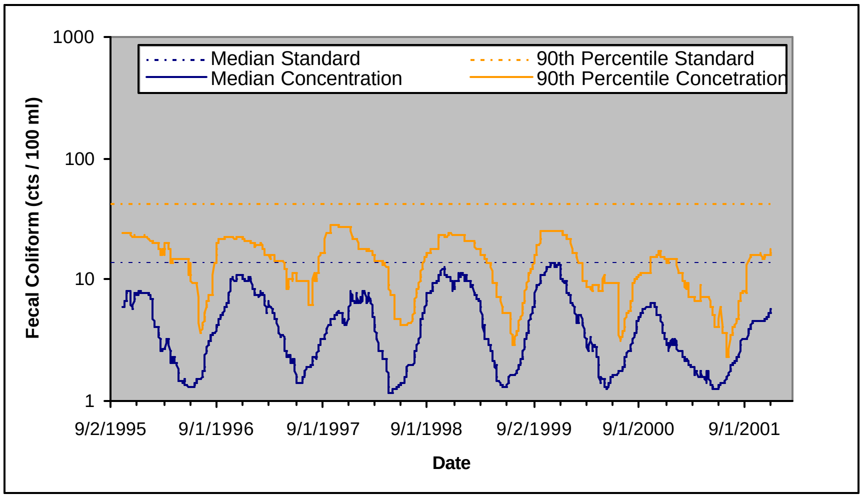


Figure 40. Predicted median and 90th percentile values after load reductions. Statistics are based on a 90-day moving window.

Direct and runoff loadings (**Table 6**) from CAFOs were reduced to zero because, by permit requirements, discharge is not allowed from these facilities, including the land used for the application of generated fertilizer. Septic tanks were also allocated zero load because properly operating systems should have no measurable discharge of bacteria. No load reductions were assigned to forest land because it is assumed that they are representative of natural, background levels.

Because of the bacterial decay, a greater allocation is assigned to pastures and developed land in the upper watershed than in the lower watershed for the Nehalem (**Table 5**). For pastures, storm runoff concentrations and direct loading were reduced with a 9:1 ratio between the lower and upper watershed. This ratio is based on the derived decay rate of 0.8 days^{-1} and the average travel time of 2.7 days between the approximate middle of the upper watershed (just upstream of Vesper) and the uppermost pasture in the lower watershed. For developed land in the lower watershed, storm runoff concentration is allocated to 500 cts / 100 ml, the same allocated concentration as pasture. In the upper watershed, the allocated concentration for developed land was computed by reducing the current load by the same percentage as the reduction allocated to pasture in the upper watershed.

Eliminating loads from WWTPs and increasing loads to the current permit median concentration limit (*E. coli*:126 cts / 100ml) did not alter the maximum median concentration by more than 1 ct / 100 ml and the difference is less than half of the standard error for the model in predicting seasonal values. Therefore, wasteload allocations beyond current permit standards are not necessary. The most sensitive period is in the fall and winter with higher flows, so minor point sources are not likely to have a large affect on the concentration.

Allocations change the major source of bacteria from pastures and CAFOs to non-anthropogenic sources (**Figure 19, 20 and 21**). Allocations are also protective of the recreation contact standard throughout the Subbasins, and should result in particular improvements on the North Fork of the Nehalem River.

Necanicum Watershed Waste Load Allocations

The waste load allocations in the Necanicum watershed were determined by lowering storm runoff concentrations and direct loading until the maximum 90-day median and 90th percentile for the modeling period (September 1995 until March 2002) met the shellfish criteria for the estuary. Land use specific allocations for storm runoff concentrations and direct loading were determined by reducing the difference between present conditions and background conditions by the same percentage (**Tables 7 and 8**). Allocations are also protective of the recreational contact standard throughout the Necanicum River (**Figure 22**).

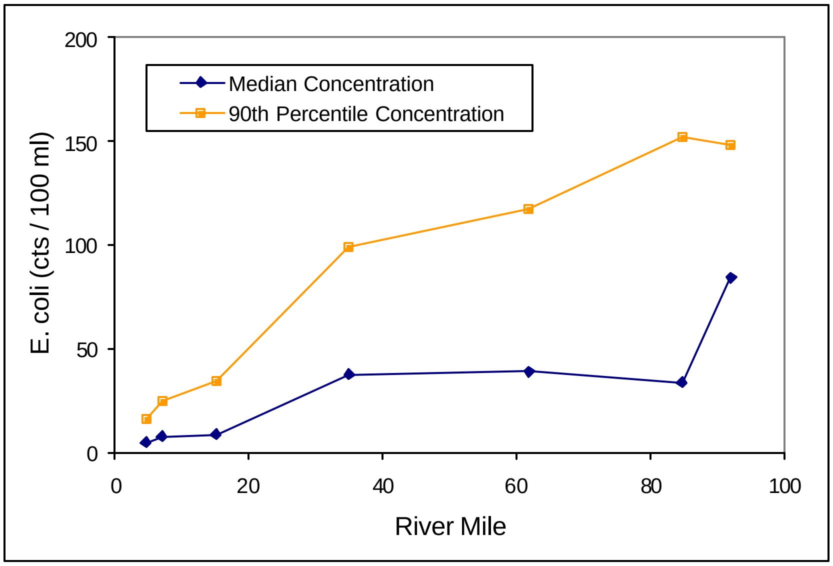


Figure 41. Profile of predicted median and 90th percentile *E. coli* concentration along the Nehalem River after allocated reductions based on Fall 2000 model results. The site near the mouth is at Wheeler.

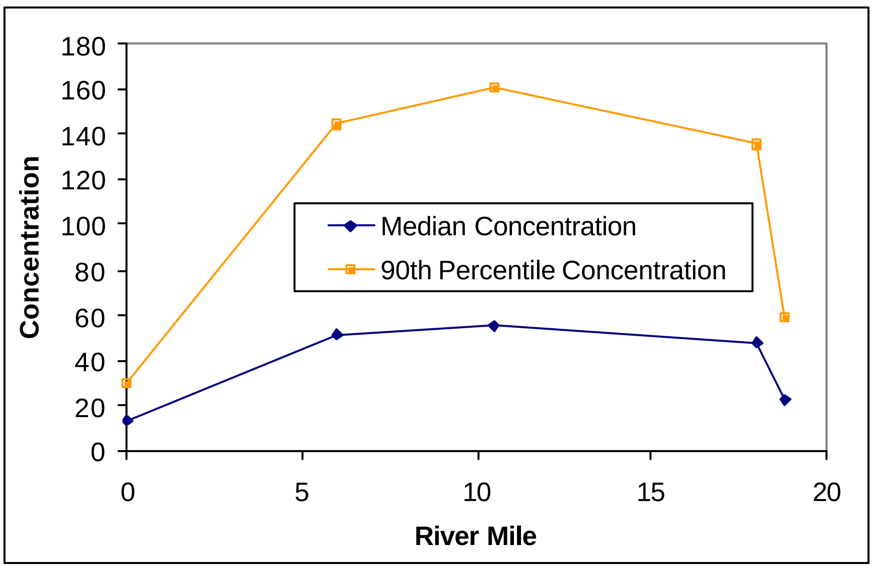


Figure 42. Profile of predicted median and 90th percentile *E. coli* concentration along the Necanicum River after allocated reductions based on Fall 2000 model results.

Clatskanie Watershed Waste Load Allocations

The waste load allocations in the Clatskanie watershed were determined by lowering storm runoff concentrations and direct loading until the maximum 90-day median and 90th percentile for the modeling period (September 1995 until March 2002) met the recreational contact criteria for the river. Land use specific allocations for storm runoff concentrations and direct loading were determined by reducing the difference between present conditions and background conditions by the same percentage (**Table 10**). These reductions will ensure the water quality standards are met throughout the Clatskanie River Watershed (Figure 23).

Table 10. Clatskanie River Subbasin storm runoff concentrations

Source – Storm Runoff	Present *E. coli* (cts / 100 ml)	Reduced *E. Coli*. (cts / 100 ml)	Reduction (%)

Pasture	10,000	7,000	30
Urban	1,400	980	30
Rural Residential	1,400	980	30
Non Anthropogenic	60	60	0

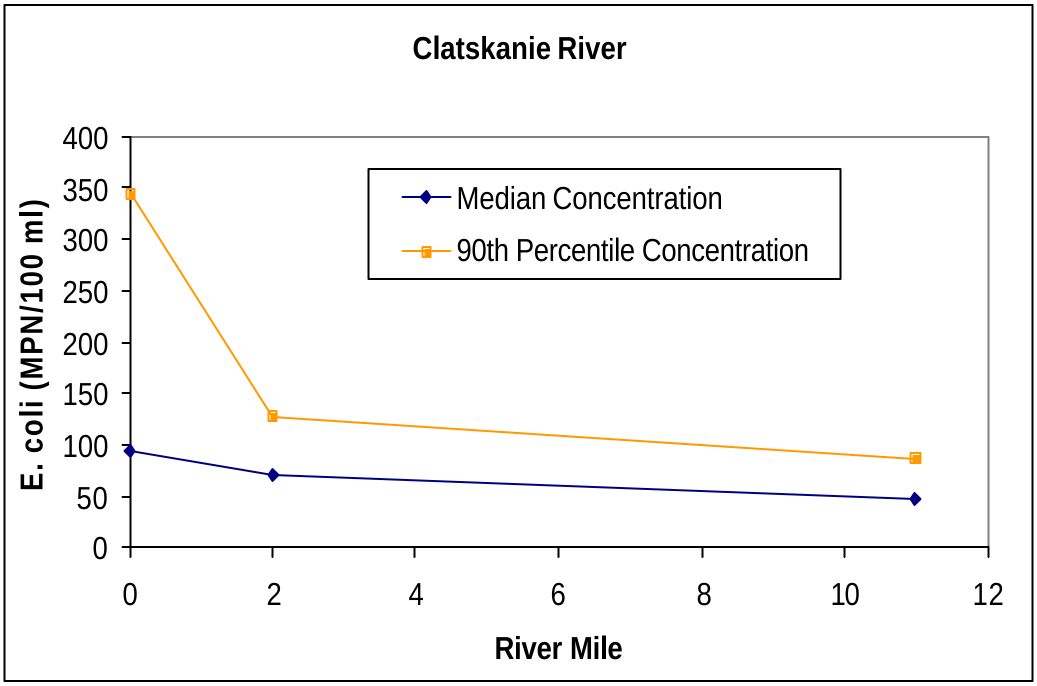


Figure 43. **Profile of predicted median and 90th percentile *E. coli* concentration along the Clatskanie River after allocated reductions based on Fall 2000 model results.**