# APPENDIX B: BACTERIA MODEL DESCRIPTION

## BACTERIA MODEL DESCRIPTION

To evaluate bacteria loading in the Tualatin Sub-Basin, an event based, unit load model was used. The model uses storm volumes, runoff concentrations for various land uses, and bacteria die off rates to predict bacteria concentration in the streams. Five major geographic databases were used in this project: soils, land use, precipitation pattern, watersheds, and distance from the stream. These five data bases were overlaid in ArcView to create a composite GIS database which was used for estimating storm volume, travel time of overland flow in the watershed, the bacteria die-off rate (a function of the travel time), and bacteria load. These parameters were modeled for all locations in the watershed. In addition, a bacteria die-off rate was incorporated for travel time instream. Each of these parameters is discussed below.

## Storm Runoff Volume

Runoff volume for each selected storm was estimated using a combination of the rational formula (Pilgrim and Cordery, 1993) and the Soil Conservation Service Curve Number (SCS CN) approach (Novotny and Olem, 1994). The rational method was used within the urban growth boundary to be consistent with the calculations used in the MS4 permit application and annual reports. The SCS curve number was used outside of the urban growth boundary to ensure that runoff would not be generated until the soil was saturated.

### RATIONAL METHOD:

The rational method is generally used to calculate the peak flow for a storm event, as follows:
Peak Flow (cfs) = $Q_P = C\ i\ A$
Where:
C = Land use runoff coefficient based on soils, slope and development (unit less)
i = Rainfall Intensity (in/hour)
A = Area (acres)

However, the rational method was adapted to calculate the total storm runoff volume by using the average rainfall intensity for the entire rainfall event and by multiplying the flow (cfs) by the number of days of the event, to generate volume in $ft^3$.

The land use runoff coefficients (McCuen 1998) were based on major land uses in developed areas, precipitation volume and hydrologic soil group (Table1). The SSURGO soil database (USDA 1998) was used to determine the hydrologic soil group. The land use data was constructed from a composite of the Regional Land Information System (RLIS) zoning (Metro 1999) and USGS Land Cover.

**Table 1: Runoff Coefficients for Developed Areas within the Urban Growth Boundary**

| Type Of Drainage Area | Runoff Coefficient (C) |
|---|---|
| Commercial: | 0.71-0.90 |
| Residential: | 0.25-0.54 |
| Industrial : | 0.67-0.88 |
| Streets: | 0.70-0.95 |

## CURVE NUMBER:

The SCS CN was used to generate the storm runoff volume outside of the urban growth boundary. The curve number calculations are as follows:

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

Where:
Q= the runoff volume (ft$^3$)
P= precipitation (inches)
S= storage (inches)

Storage is calculated as follows:

$$S = \frac{1000}{CN} - 10$$

The curve numbers (CN) are read from SCS tables and vary by land use, hydrologic soil group, percent ground cover and antecedent moisture conditions (AMC). Table2 summarizes CNs for various land uses under average moisture conditions with good vegetation cover (McCuen 1998).

**Table 2: CNs for Land Uses outside of the urban growth boundary**

| | Curve Numbers for Hydrologic Soil Group | | | |
|---|---|---|---|---|
| **Land Use** | **A** | **B** | **C** | **D** |
| Open spaces | 39 | 61 | 74 | 80 |
| Streets and Roads | 83 | 89 | 92 | 93 |
| Commercial | 89 | 92 | 94 | 95 |
| Residential | 51 | 68 | 79 | 84 |
| Pasture | 39 | 61 | 74 | 80 |
| Forest | 32 | 58 | 72 | 79 |

The curve numbers can be adjusted for the level of moisture in the soil or the antecedent moisture condition (AMC). The AMC is determined by examination of precipitation records for the basin and are described below (McCuen 1998):

Condition I: Soils dry but not to wilting point; satisfactory cultivation has taken place
Condition II: Average conditions
Condition III: Heavy rainfall, or light rainfall and low temperatures have occurred within the last five days; saturated soil

**Table 3: Definitions of Antecedent Moisture Conditions**

| | **Total 5 day antecedent rainfall (inches)** | |
|---|---|---|
| AMC | Dormant Season | Growing Season |
| I | Less than 0.5 | Less than 1.4 |
| II | 0.5 - 1.1 | 1.4 -2.1 |
| III | Over 1.1 | Over 2.1 |

The CN for average conditions is adjusted for the AMC according to the following equations:

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)}$$

Storm event rainfall was analyzed from 2 gages in the Tualatin basin; Hydromet-Agrimet gage at Forest Grove and Beaverton 1NW gage (station number 350595). Rainfall distribution would be expected to vary due to orographic effects. The storm event rainfall distribution was estimated using spatial patterns of precipitation in the watershed from long-term precipitation maps generated by the PRISM model (Daly, et al. 1994).

# LAND USE AND POINT SOURCE CONCENTRATION

Estimates of bacteria concentrations for each land use were taken from several sources.

**Forest Land Use:** The forest land use concentration was determined from DEQ sampling conducted in the Nestucca basin. Runoff samples from forested lands were recorded as 1 MPN/100 ml *E*. coli.
**Commercial Land Use:** Values reported in the 1999 Stormwater Annual report were used (submitted by United Sewerage Agency of Washington County, Washington County and Oregon Department of Transportation, August 1999). Values ranged from <15 to 8000 count/100 ml *E*. coli.
**Residential Land Use:** Values reported in the 1999 Stormwater Annual report were used (submitted by United Sewerage Agency of Washington County, Washington County and Oregon Department of Transportation, August 1999). Values ranged from 12 to 4200 count/100 ml *E*. coli.
**Industrial:** Values reported in the 1999 Stormwater Annual report were used (submitted by United Sewerage Agency of Washington County, Washington County and Oregon Department of Transportation, August 1999). Values ranged from 23 to 8000 count/100 ml *E*. coli
**Agricultural:** Agricultural land use was assumed to include manure application on fields as well as animal grazing. Runoff concentrations were taken from DEQ sampling in the Nestucca basin. Runoff concentrations from confined animal feeding operations ranged from 30 to greater than 24000 MPN/100 ml *E*. coli.
**Point Sources:** Median flows for the USA treatment plants were calculated from Discharge Monitoring Reports covering the period of 1995 to 1999. Median *E*. coli concentrations were calculated as 1 count/100 ml for each of the treatment plants.
**Septic Systems:** No sanitary survey information was available for the Tualatin Sub-Basin. Failing systems were simulated in the areas of the basin not serviced by the USA treatment plants. Failing septic systems were placed in the model using a random number generator and a 5% failure rate. Using data from "ODEQ Final Report Oregon On site Experimental Systems Program, December 1982", the flow and concentration of septic tank effluent was estimated. It was assumed that 100% of the effluent flowed to the rivers. The resulting load is calculated using the following equation:
(200 gallons/day)(20000 count/100 ml)(1ft$^3$/7.48 gallons)(1 day/24 hours)(1 hour/60 minutes)(1 minute/60 seconds) = 6.2 (count/100 ml)(ft$^3$/sec)
**Streets and highways:** *E*. coli values from Oregon Department of Transportation sampling, conducted in the City of Portland, were used (NPDES MS4 Permit #101315, Annual Report August 30, 1996).

# BACTERIA DIE OFF

The bacterial die off rate during overland flow was estimated based on the travel time of the water to the major streams. 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 - in Tillamook we use the distance to major streams)

n = Manning's n

i = Rainfall Intensity (mm/hr)

S = Slope (m/m)

Slope was taken from the SSURGO soils database. The Manning's n values were based on land uses (Chow et al, 1988). The slope length was estimated by creating buffer zones away from the stream.

Decay is based on the first order decay equation. According to Moore (1982) there is a lack of data in the literature on correlation of other decay models to die-off in soil and water systems.

First order decay (Moore, 1982):

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

Where: $N_t$ = number of bacteria at time t

$N_o$ = number of bacteria at time o

t = time in days

k = first order or die-off rate constant

The first order decay rates can be adjusted in the model but typically ranges between 0.01 and 2.0 (Moore, 1982). A value of 0.6/day was used for the overland decay rate, the average of the decay rates reported for dairy manure applied to soil (Moore, 1988).

An additional die-off rate was incorporated to account for decay that occurs as the bacteria travels downstream. The instream bacteria die-off was adjusted for temperature using the following equation (Tchobanoglous, 1985).:

$$(K)_T = (K)_{20}(\Theta)^{T-20}$$

Where:

$\Theta$ is the temperature coefficient

$K_T$ = decay rate at temperature T

$K_{20}$ = decay rate at 20°C

Using laboratory data (Moore 1982), the average Θ was calculated to be 1.1. Theta was then applied to a field determined K (from Moore 1982) using the average temperature of 9°C recorded in Gales Creek during the October 1999 sampling event. The resulting decay rate of 3 was used in the October 1999 calibration. This decay rate was also used for the winter storm allocations. The average instream system potential temperature predicted in the temperature TMDL was used to calculate the decay rate for the summer allocations.

| Basin | pre allocation temperature C | pre allocation decay rate | post allocation Temperature C | post allocation Decay rate |
|---|---|---|---|---|
| Tualatin- Lee Creek to Scoggins dam (scoggins 5 field) | 18.9 | 12 | 14.4 | 7 |
| Tualatin -Scoggins dam to Middle Tualatin confluence (scoggins 5th field) | 11.9 | 5 | 10.8 | 4 |
| Gales Creek | 22.2 | 17 | 15.6 | 8 |
| McKay Creek | 18.9 | 12 | 15.0 | 7 |
| E.F. Dairy Creek | 19.4 | 13 | 13.9 | 6 |
| W.F. Dairy Creek | 21.1 | 15 | 16.7 | 9 |
| Rock Creek | 19.7 | 13 | 15.0 | 7 |
| Fanno Creek | 18.3 | 11 | 13.6 | 6 |
| Middle and Lower Tualatin basins (not including Fanno Creek) | 17.8 | 10 | 14.6 | 7 |

# MODEL CALIBRATION

Two storm events were chosen for flow and bacteria calibration; June 1998, sampled by USGS in Fanno Creek, in October 1999 sampled by DEQ in Gales Creek. The June event resulted in a brief, steep hydrograph at the gage on Fanno Creek at 56$^{th}$ (Figure 1). The watershed is predominantly residential (93.5%), with commercial (2%)and open space (4%) as well. The instream concentrations reached *E*. coli concentrations as high as 36000 *E*. coli/100 ml in Fanno Creek at 56$^{th}$ (Figure 2). As discussed in the model calibration section, sampling conducted under the MS4 permit reported values for residential land uses in the range of 12 to 4200 cts/100 ml *E*. coli. However, to attain instream concentrations recorded in the Fanno Creek watershed, runoff concentrations would have to be at least an order of magnitude greater than those recorded in the MS4 annual reports.

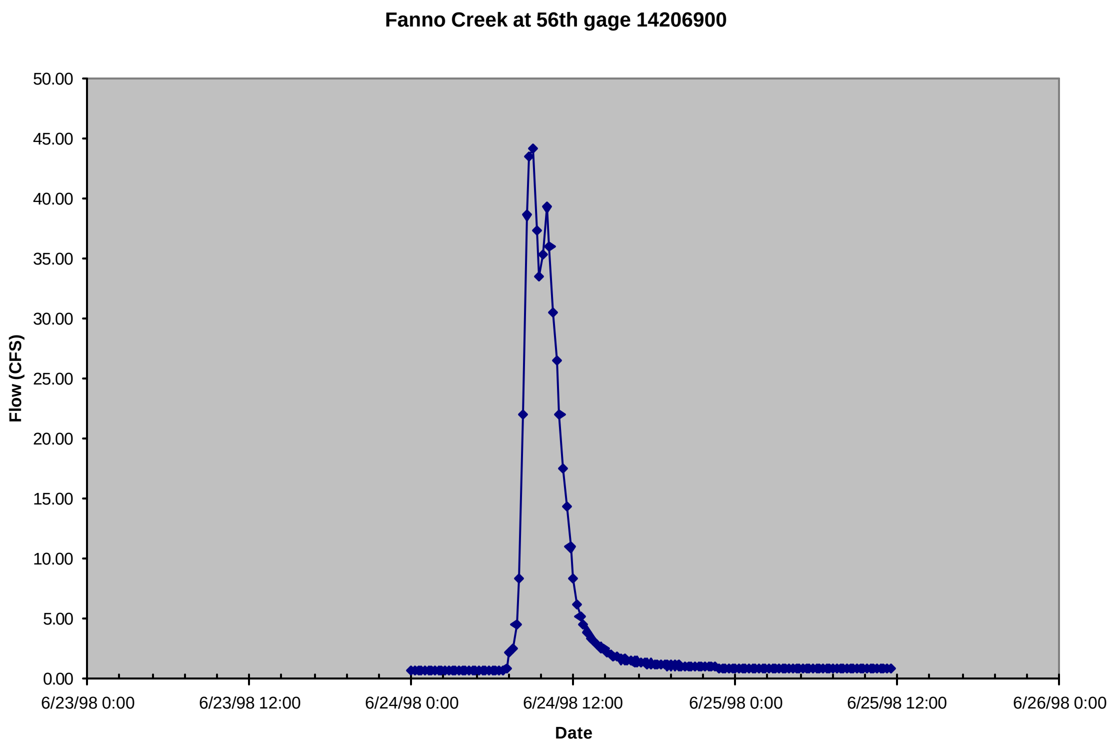


**Figure 1: Hydrograph from Fanno Creek at 56th (USGS gage 14206900)**

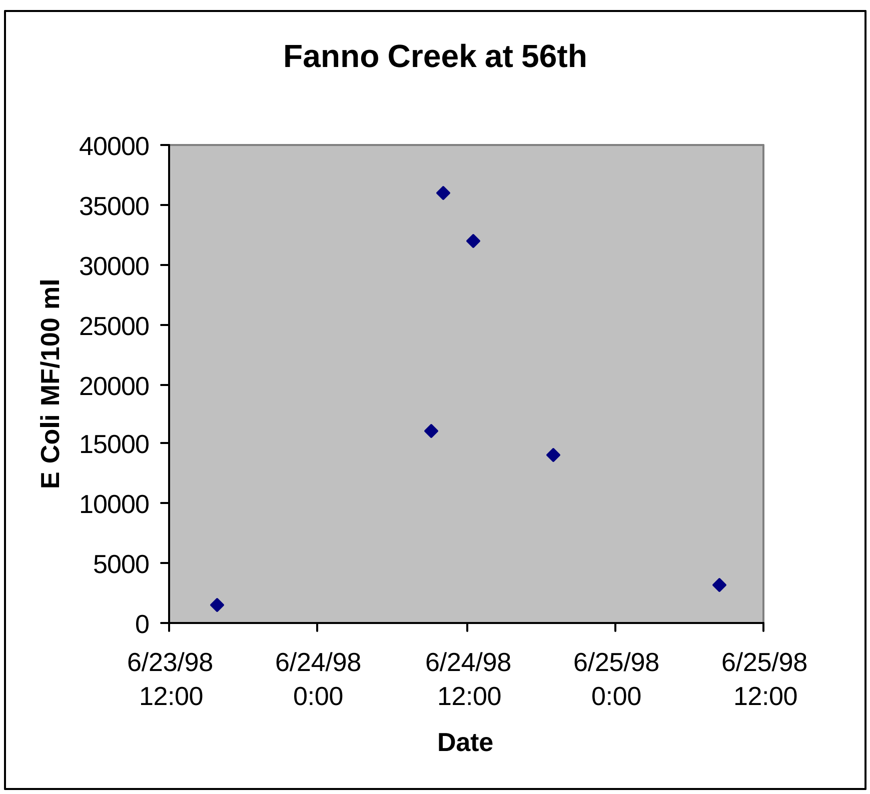


**Figure 2: Bacteria Pollutograph from Fanno Creek at 56th (USGS data)**

The October storm event generated runoff from the forested areas in the Gales Creek watershed, as well as the impervious areas lower in the watershed. A gage at old highway 47 recorded the storm hydrograph for the sampling period (Figure 3). Bacteria concentrations reached almost 4000 cts/100 ml at Gales Creek upstream of Ritchie Road (Figure 4).

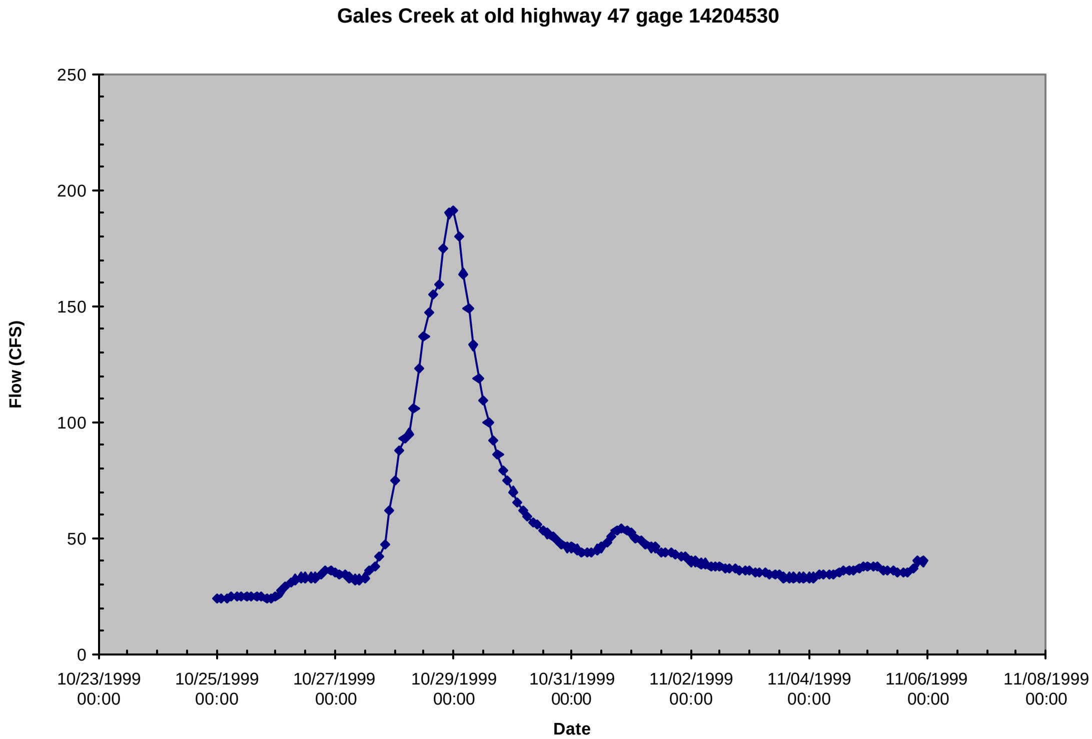


**Figure 3: Hydrograph recorded at Gales Creek at old highway 47 (WRD gage 14204530)**

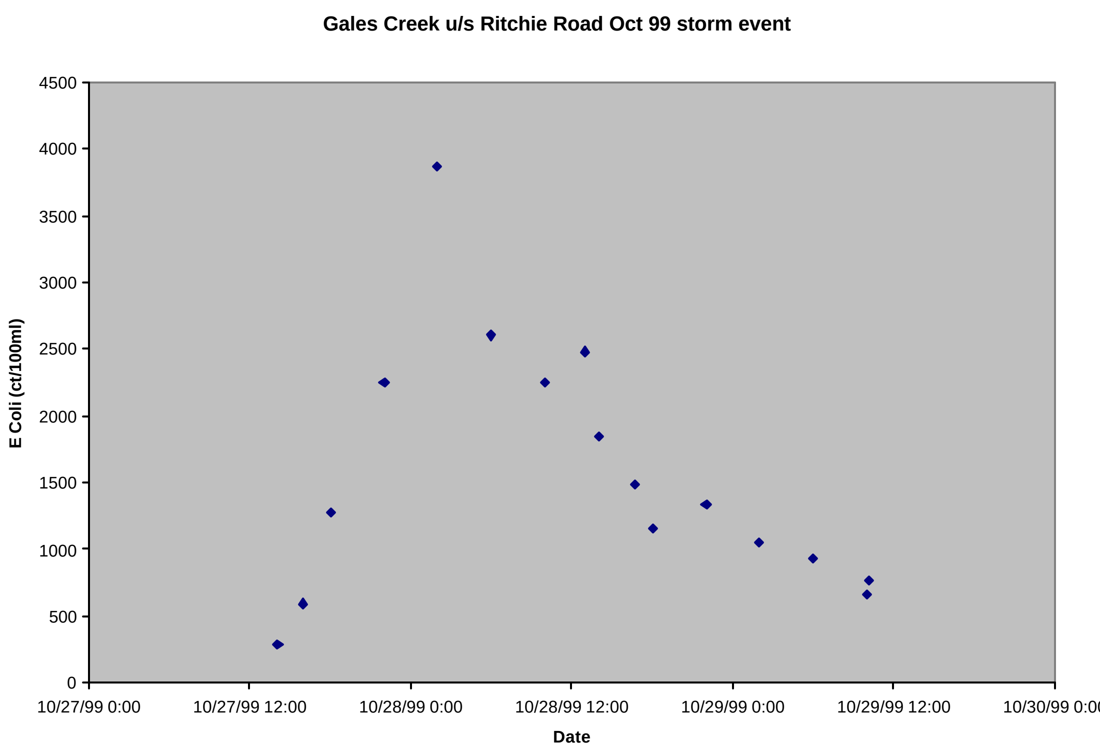


**Figure 4: Bacteria Pollutograph from Gales Creek upstream of Ritchie Road (DEQ data)**

As described previously, the flow model predicts the storm runoff volume. To compare modeled storm volumes to flow gage measured volumes, baseflow was added to the modeled storm volume. Baseflow was estimated using the unit hydrograph method (Dunne et al 1978*).* Several summer and winter storm event hydrographs were analyzed and the average baseflow for each season were used in the model. The baseflow, in $ft^3$/sec, was multiplied by the number of days in the storm event, to yield the storm baseflow volume, in $ft^3$. The modeled storm volume was compared to the measured storm volume for the duration of the hydrograph as recorded at flow gages at several points in the basin. Agreement was calculated using a measure of the relative percent difference (RPD) and the % error. Rainfall was adjusted until the flows with the lowest measures of error were attained. The error calculations are as follows:

% error = $(F_O - F_S)/F_O$;

$$RPD = \left(\frac{(F_O - F_S)}{(F_O + F_S)/2}\right) * 100$$

The calibrations with the lowest RPD and % error for the Gales Creek October 1999 storm are presented in Table 4. Flow calibration results for Fanno Creek June 1998 storm are presented in Table 5.

**Table 4: Error estimates for October 1999 storm volume calibration**

| 5th field watershed | 6th field watershed | gage location | gage number | RI | Prec. | Hydrograph storm length | Measured Storm volume(ft3) | Model volume (ft3) | ABS | % ERROR |
|---|---|---|---|---|---|---|---|---|---|---|
| Gales Creek | Gales Creek below Ritchie Up | At old highway 47 | 14204530 | 0.04 | 2.7 | 3.5 | 28353600 | 26007838 | 0.0863024 | 0.0827324 |
| Dairy Creek | Lower Mickey Creek | at highway 8 | 14206200 | 0.04 | 2.7 | 4.5 | 59554800 | 63722142 | 0.0676094 | -0.0699749 |
| Rock Creek | Middle Rock Creek Upper | at highway 8 | 14206450 | 0.023 | 1.41 | 1.92 | 42426000 | 41188169 | 0.0296082 | 0.0291762 |
| Scorns | Dilly Creek Lowe | Teal near Dilly | 14203500 | 0.039 | 2.93 | 2.67 | 46714179 | 47100811 | 0.0082424 | -0.0082765 |
| Middle Tualatin | bottom of Middle Tualatin | Golf Course Road | 14204800 | 0.04 | 2.7 | 3.5 | 82526400 | 81351565 | 0.0143379 | 0.0142359 |
| Lower Tualatin | Sylvan Creek Upper | Fanno Creek at 56th | 14206900 | 0.03 | 1.25 | 1.63 | 1141482 | 996792 | 0.1353339 | 1.27E-01 |
| Lower Tualatin | Fanno Creek | Fanno Creek at Durham | 14206950 | 0.03 | 1.25 | 1.63 | 1.79E+07 | 21427539 | 0.178240757 | -1.96E-01 |
| Lower Tualatin | Lower Tualatin River Upper | West Linn | 14207500 | 0.03 | 1.25 | 7 | 307689499 | 324682351 | 0.053743227 | -5.52E-02 |

**Table 5: Error estimates for June 1998 storm volume calibration**

| 5th field watershed | 6th field watershed | gage location | gage number | RI | Prec. | Hydrograph storm length | Measured Storm volume(ft3) | Model volume (ft3) | ABS | % ERROR |
|---|---|---|---|---|---|---|---|---|---|---|
| Lower Tualatin | Sylvan Creek Upper | Fanno Creek at 56th | 14206900 | 0.012 | 0.50 | 1.90 | 591922 | 553734 | 0.0666657 | 6.45E-02 |

Land use bacteria concentrations were adjusted to meet the instream bacteria concentrations, calculated as geometric means. Tables 6 and 7 summarize the concentrations used in the calibrations.

**Table 6: Calibrated *E*. coli Concentrations for Land Uses for Oct. 1999 Gales Cr. sampling**

| Land Use | Oct 99 Calibrated *E*. coli Runoff Concentration (cts/100ml) |
|---|---|
| Forest | 1 |
| Commercial | 255 |
| Residential | >5000 |
| Industrial | 1200 |
| Cropland and Pasture | 20000 |
| Orchards, Groves, Vineyards | 1000 |
| Streets and Highways | 1000 |

**Table 7: Calibrated *E*. coli Concentrations for Land Uses for June 1998 Fanno Cr. sampling**

| Land Use | June 1998 Calibrated *E*. coli Runoff Concentration (cts/100ml) |
|---|---|
| Forest | 1 |
| Commercial | 15000-20000 |
| Residential | 15000 |
| Industrial | 12000-15000 |
| Cropland and Pasture | 1[1] |
| Orchards, Groves, Vineyards | 1[2] |
| Streets and Highways | 12000 |

To calculate the bacteria load, the runoff volume was multiplied by the bacteria concentration for each land use. The resulting load was decayed as it flowed overland to the receiving waterbody. The instream concentration was calculated by dividing the bacteria load by the runoff volume. Instream decay was incorporated as the bacteria flowed downstream between watersheds. The modeled storm average *E*. coli concentration was compared to the measured *E*. coli geomean for each sampled site (Tables 8 and 9).

**Table 8: Comparison of Measured and Modeled *E*. coli Concentration Oct. 1999 storm event**

| Instream Sampling Location | Measured *E*. coli geomean | Modeled *E*. coli concentration (storm average) |
|---|---|---|
| Gales Cr. at Hwy. 6 Milepost 36.95 | 40 | 55 |
| Gales Cr. at Parson Rd. | 798 | 821 |
| Gales Cr. u/s Ritchie Rd | 1289 | 250 |

[1] Cropland and pasture does not generate runoff in this storm event

[2] About 1% of Summer Creek is orchard land. Orchards do not generate runoff in this storm event.

**Table 9: Comparison of Measured and Modeled *E*. coli Concentration June 1998 storm event**

| Instream Sampling Location | Measured *E*. coli geomean | Modeled *E*. coli concentration (storm average) |
|---|---|---|
| Fanno Creek at 56th | 10363 | 9837 |
| Fanno Creek near Allen | 5303 | 7922 |
| Fanno Creek at Durham | 4041 | 1509 |

In both calibrations, the measured geomean was not attained at the lower sites in the watershed. This may be due to residential area contributing more runoff and bacteria load than modeled and/or the presence of unidentified sources.

## ALLOCATIONS:

Allocations were set for 2 storm events: a winter storm event in which the cropland and forests would be saturated and contribute runoff and a summer event in which the soil was dry and only impervious areas contribute to instream concentrations (Table 10). The summer precipitation of 0.11 inches was chosen because it is the most common summer precipitation event expected to result in runoff.

The winter precipitation of 1.96 inches was selected for the following reasons:

1. A total precipitation of 1.96 inches is necessary to generate runoff from pervious land uses (i.e. forestry and cropland)
2. 4 days of rainfall would allow for saturated soil conditions
3. 90% of 4 day storms had a precipitation of 1.96 inches or less (analysis of Beaverton precipitation gage, period of record 1972-1999).

The allocations were set to achieve equitable E. coli concentrations for each land use, with the exception of forestry. Forested runoff was allocated a concentration of 10 E. coli counts per 100 ml based on the observed concentrations.

Allocations were set to attain the geomean of 126 *E*. coli at the mouths of each of the 5th field watersheds. Septic systems are given an allocation of zero. Failing septic systems are to be corrected. The land use based allocations are summarized in Tables 17, 18, 21 and 22 of the main TMDL document.

**Table 10: Parameter Values for Winter and Summer Allocations**

| Basin | pre allocation Temperature (( | pre allocation Decay rate | post allocatio Temperature (( | post allocatio Decay rate |
|---|---|---|---|---|
| Tualatin- Lee Creek to Scoggins dam (scoggins 5th field) | 18.9 | 12 | 14.4 | 7 |
| Tualatin -Scoggins dam to Middle Tualatin confluence (scoggins 5th field) | 11.9 | 5 | 10.8 | 4 |
| Gales Creek | 22.2 | 17 | 15.6 | 8 |
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| Fanno Creek | 18.3 | 11 | 13.6 | 6 |
| Middle and Lower Tualatin basins (not including Fanno Creek) | 17.8 | 10 | 14.6 | 7 |

## MARGIN OF SAFETY:

The margin of safety is not explicitly defined. The margin of safety is addressed by the following conservative assumption:

1. The allocations are set to meet the geomean of 126 *E*. Coli at the mouth of each 5$^{th}$ field watershed. To determine compliance with the criteria, the 30 day log mean should be calculated, which would likely include dry weather sampling as well as wet weather sampling. Because the allocations are set for storm events, the allocations are more stringent than if they had been calculated based on dry weather as well.