TO: File: Russian River; TMDL Development and Planning

FROM: Steve Butkus

DATE: January 18, 2013

SUBJECT: ASSESSMENT OF FECAL INDICATOR BACTERIA CONCENTRATIONS MEASURED DRAINING FROM AREAS WITH DIFFERENT LAND COVERS

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The North Coast Regional Water Board staff are developing Russian River Total Maximum Daily Loads (TMDLs) for pathogen indicators to identify and control contamination impairing recreational water uses. Potential pathogen contamination has been identified in the lower and middle Russian River watershed leading to the placement of waters within these areas on the federal Clean Water Act Section 303(d) list of impaired waters. The contamination identified has been linked to impairment of the contact recreation (REC-1) and non-contact recreation (REC-2) designated beneficial uses. Health advisories for these waters have been published and posted by Sonoma County and the City of Santa Rosa authorities.

A study conducted by of the U.C. Davis Aquatic Ecosystems Analysis Laboratory (Shilling et al. 2009; Viers et al. 2009) found that runoff from different land uses and weather periods showed different concentrations of fecal indicator bacteria (FIB). Regional Water Board staff conducted a source analysis study for the development of the Russian River Pathogen TMDL. The study was organized into individual tasks and sampling plans designed to collect information which will address the identified management questions (Fadness and Butkus 2011). Task 3 of the study involved the collection of water samples to evaluate the influence of different land uses on FIB concentrations. The objective of the task was to assess the relative magnitude and variability of FIB concentrations in waters draining from each of the major land uses during both dry and wet weather periods in the middle and lower Russian River watershed. Results were documented in a report by the NCRWQCB (2012).

## Land Cover Categories

Five (5) land cover categories were selected to assess potential differences in FIB concentrations in runoff draining from catchment areas of each land cover. These land cover categories were based on the National Land Cover Dataset (Fry et al. 2011) and Urban Service Areas (PRMD 2010). The land cover categories were defined through remote sensing by Anderson et al. (1976):

1. Forest Land – Areas with a 10 percent or more tree-crown areal density (crown closure percentage).

2. Shrubland –Areas where the potential natural vegetation is predominantly grasses, grass-like plants, forbs, or shrubs. Anderson et al. (1976) previously defined this land cover as “Rangeland”. These areas do not include pastures or dry croplands.

3. Agriculture – Areas were defined by visual indications of agricultural activity through distinctive geometric field or road patterns and the traces produced by livestock or mechanized equipment.

4. Developed Sewered - Urban and residential areas identified by Fry et al. (2011) where much of the land is covered by structures including cities, towns, villages, strip developments along highways, transportation, power, and communications facilities. Residential land uses range from low density (where houses are on lots of more than an acre) to high density, multiple-unit structures. The boundaries of the Urban Service Areas (PRMD, 2010) were used to identify those urban and residential areas that are sewered to receive domestic wastewater treatment.

5. Developed Onsite Septic – Residential land uses identified by Fry et al. (2011) where the houses are outside of the boundaries of the Urban Service Areas (PRMD, 2010) and assumed to use onsite wastewater treatment systems (i.e. septic systems).

Three (3) catchments were selected to represent each land cover category (Table 1). Selection of these catchments was based both on percentage of land cover and catchment size. Selection of very small catchments would increase the relative percentage of each land cover. However, the selection of catchments that are too small would not have adequate stream flow for dry weather sampling. As the catchment size increases to where dry weather stream flow exists for sampling, the relative percentage of the land cover category decreases. The selection of sampling locations attempted to find the smallest catchment for each land cover category that contained dry weather stream flow. All selected locations represented at least 50% or greater land coverage in the catchment, except for the catchments representing developed onsite septic areas. The low relative percentage for this land cover category was due to other land cover types, mostly agricultural.

**Water Sample Collection and Analysis**

Three (3) water samples were collected at fifteen (15) locations within the Russian River watershed, during both wet and dry weather periods, resulting in six (6) samples for each land use category. *Enterococcus, Escherichia coli* (E. coli) and total coliform bacteria concentrations were measured by the Regional Water Board Microbiology Laboratory using the Enterolert® and Colilert® microbial tests (IDEXX 2001). Total *Bacteroides* bacteria concentrations were measured by the Sonoma County Public Health Laboratory using quantitative real time polymerase chain reaction (qPCR) methods. Host-specific *Bacteroides* bacteria concentration measurements were made for human and bovine animal hosts. The percentage of the host-specific *Bacteroides* bacteria in the samples were derived from the measured total *Bacteroides* bacteria concentrations.

Analysis of water samples for stable isotopes of nitrate (SIA) was also conducted at the U.C Davis Stable Isotope Facility. SIA was measured to evaluate nitrate for relative source differences in oxygen (δ18O) and nitrogen (δ15N). These differences can help identify the source of the water associated with the FIB samples. Stable isotope analyses figures are compared to typical values associated with various sources (Michener and Lajtha 2007).

**Censored Data Estimation**

Several of the analyses resulted in FIB concentrations that were either below or above the reporting limits of the analytical test. Measurements analyzed beyond the reporting unit are called “censored” data (Helsel and Hirsch 2002). Estimates of summary statistics, which best represent the entire distribution of data, both below and above the reporting limit, are needed to accurately analyze environmental conditions. As such, unbiased estimates of the censored data are needed to assess the variation in measured FIB concentrations.

Regression on order statistics (ROS) was applied to estimate censored data prior to use in statistical hypothesis tests. ROS is based on the modified probability plotting (Helsel 1990; Helsel and Cohn 1988). The approach fits a regression line to log transformed observation values above the reporting limit against their standard scores. The regression line is used to estimate the values of each censored value. The data are then transformed back to the measurement unit. The fitted distribution is used only to extrapolate the measurement values below the analytical reporting limit. These extrapolated values are not considered estimates for specific samples, but are only used collectively to estimate summary statistics.

## Assessment Methods

Visual comparisons and statistical hypothesis tests were made between different groupings of the measured FIB concentrations and SIA results. Distributions of the measured FIB concentrations are compared visually using box and whisker plots. The boxes represent the interquartile range of the distribution around the median and the whiskers represent the 10th and 90th percentiles. Hypothesis tests were considered statistically significantly different if the resulting probability of rejecting the null hypothesis was equal or lower than $\alpha = 0.05$.

The Mann-Whitney U statistical hypothesis test was applied to assess the difference between the distributions of FIB concentrations measured draining from two different land cover types or weather periods. The Mann-Whitney U Test is a non-parametric test for assessing whether two samples of observations come from the same distribution (Helsel and Hirsch 2002). The test is similar to performing an ordinary parametric two-sample t test, but is based on ranking the data set. This statistical test is a nonparametric (i.e., distribution-free) inferential statistical method. The test makes no assumption of the frequency distributions. Nonparametric methods are the most appropriate approach for assessing water quality data which can have widely varying frequency distributions.

The Kruskal-Wallis statistical hypothesis test was used to assess if any sample showed a statistical difference between FIB and *Bacteroides* bacteria concentrations draining from the five land cover categories. The Kruskal-Wallis test is a one-way analysis of variance conducted using ranked data (Helsel and Hirsch 2002). The test is an extension of the Mann–Whitney U test to three or more groups. The parametric equivalent of the Kruskal-Wallis test is the one-way analysis of variance (ANOVA). When the Kruskal-Wallis test indicates significant results, then at least one of the land cover distributions is different from the other land cover distributions in the group.

## Results

*Dry versus Wet Weather Samples*

Figures 1 and 2 present the distribution of FIB and *Bacteroides* bacteria concentrations during both dry and wet weather periods. The visual comparisons between the distributions suggest that higher concentrations of bacteria are found in runoff during wet weather periods as compared to dry weather periods. Table 2 shows the results of applying the Mann-Whitney U statistical hypothesis test to evaluate the difference between concentrations measured during the dry and wet weather periods. The hypothesis tests confirm the visual observation that there is a statistically significant difference between all dry and wet weather FIB and *Bacteroides* concentrations. Wet weather concentrations are also statistically significantly higher than dry weather concentrations of FIB and *Bacteroides* bacteria.

*Land Cover Samples*

Assessment of the concentrations between different land covers was conducted separately for dry and wet periods since there was a significant difference in concentration between the two weather periods. Figures 3 – 8 present the distributions of the measured FIB concentrations (*Enterococcus, E. coli* and total coliform bacteria) for each land category. These distributions are visually compared to the California Department of Public Health criteria for posting beaches for fecal contamination (CDHS, 2006). Beach posting is recommended when indicator organisms exceed any of the following single sample levels; total coliforms: 10,000 organisms per 100 ml (org/100mL); *E. coli*: 235 org/100mL; and *Enterococcus*: 61 org/100mL. Figures 9 – 14 present the distributions of the measured *Bacteroides* bacteria (Total, Human-specific, Bovine-specific) for each land category. Criteria for safe recreational levels of *Bacteroides* bacteria have not been developed for comparisons to measured concentrations. .

The visual comparisons suggest that there are differences in the runoff FIB and *Bacteroides* bacteria concentrations between land covers. In particular, Forest Lands appear to have consistently lower concentrations than the other land cover categories assessed. Table 3 shows the results of Kruskal-Wallis statistical hypothesis test to evaluate the difference between concentrations measured in runoff between land covers. The hypothesis tests confirm the visual observation that there is a statistically significant difference between the land covers for FIB concentrations (*Enterococcus, E. coli* and total coliform bacteria). No statistically significant difference was found for either *Bacteroides* bacteria concentrations or percent animal-specific host in runoff between all land covers.

The Kruskal-Wallis statistical hypothesis test only assesses if the runoff is different between all five land cover categories. The test does not evaluate which land covers have runoff concentrations different from the other land covers, only that they are different. The Mann-Whitney U statistical hypothesis test evaluates the difference in runoff concentrations measured between two specific land covers. Tables 4 – 11 show the resulting statistical probabilities from the application of the Mann-Whitney U hypothesis test. Table 12 summarizes those pairwise comparisons where the probabilities showed a statistically significant different between the land cover runoff concentrations. These tests confirm the visual comparison in Figures 3 – 14 that show that runoff from forest lands is different in concentrations than runoff from the other land covers. In addition, runoff concentrations from shrubland and agriculture are different in FIB concentrations draining from developed areas (i.e., both sewered and onsite septic areas). However, no difference was found between *Bacteroides* bacteria concentrations or percent animal-specific host in runoff between shrublands or agriculture and developed areas. There was no difference observed in runoff between developed areas for most indicator bacteria.

The large differentiation of runoff concentrations between forest land and the other land covers may be due to the relative amount of other land covers within each sampled catchment (Table 1). The sampled Forest Land catchments only had 11% of other land uses. The catchments sampled for the developed sewered areas also contain many parcels that are not connected to the municipal wastewater treatment system and still rely on onsite septic systems. The developed septic catchments had 79% of other land uses, mostly agriculture. These mixed land uses in many of the selected catchments may account for not observing larger differences in runoff concentrations between the different land covers. The limited sample size may have also limited the ability to observe a difference given the large variability of concentrations for several of the land covers (i.e., shrublands). Also, the selected catchments may not be fully representative of runoff concentrations within the whole watershed since they were selected judgmentally, and not probabilistically.

*Stable Isotope Analysis*

SIA measurements of oxygen and nitrogen were assessed to help identify the source of the water associated with the bacteria samples. The SIA results were compared to typical values of δ18O and δ15N of nitrate (Figure 19). There were no apparent differences between dry and wet period samples. Most of the samples fell within the range of a soil source of nitrate derived from ammonia through nitrification. These sources of nitrate are likely from erosion. There are only two of the samples had δ18O values above 15‰ and δ15N below 5‰. These samples were likely from nitrate fertilizer and were collected from agricultural and sewered areas.

Four of the samples were in the range of nitrate from manure or septic waste. These samples were collected during wet weather and from the developed lands (both onsite septic and sewered areas) and are likely from domestic wastewater. Untreated animal (i.e. Human) waste has high δ15N relative to atmospheric air which is used as the standard since it remains constant at 0.366% (Junk and Svec 1958). Studies have shown that atmospherically-derived nitrogen and fertilizer nitrogen typically have light δ15N values whereas animal-derived nitrogen (such as manure or septic-tank effluents) is typically considerably heavier (Kendall 1998). The observation of suggests that storm events may be transporting untreated domestic wastewater into receiving waters.

**Findings**

Based on the assessments of FIB variability presented in this memorandum, Regional Water Board staff can make the following findings:

- There is a statistically significant difference between all dry and wet weather FIB and *Bacteroides* bacteria concentrations. Median wet weather concentrations are much higher than dry weather concentrations.

- Runoff concentrations from forest lands are statistically significantly different than runoff from the other land covers. Forest lands appear to have consistently lower concentrations of FIB and *Bacteroides* than the other land cover categories assessed.

- Runoff concentrations from shrubland and agriculture are statistically significantly different in FIB concentrations than runoff draining from developed areas (i.e., both sewered and onsite septic areas). Shrubland and agricultural areas appear to have consistently lower concentrations of FIB than runoff draining from developed areas.

- There is no statistically significant difference between *Bacteroides* bacteria concentrations or percent animal-specific host in runoff between shrublands or agriculture and developed areas.

- There is no statistically significant difference in runoff between developed areas for most indicator bacteria.

- SIA results showed that most of the nitrate measured in samples collected with bacteria samples was from soil, likely carried into the water column through rainfall-induced erosion. Several of the samples collected during wet weather in developed areas were likely derived from domestic wastewater.

- The mixed land uses in many of the selected catchments may account for relatively small differences observed in runoff concentrations between most land covers, with the exception of forests lands which had FIB concentrations much lower that runoff from the other land uses. The catchments selected for sampling forest lands had the lowest mixed land covers relative to the catchments used for the other land covers. Selection of smaller catchments would decrease the percent of mixed land uses, but would not likely contain dry weather flows.

- Additional sampling for pathogen indicators is recommended to further evaluate any differences between in runoff from sewered areas and areas with onsite septic systems. The size of the selected catchments should be reduced to remove as many mixed land uses as possible. The sampling should occur during wet weather since the SIA suggested that wastewater transport had occurred. The smaller catchment size will also assure that catchments have adequate flow volume to sample.

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**TABLES**

Table 1. Laguna Watershed Catchments Selected to Represent Land Cover Categories.

| Land Cover Category | Catchment Stream | Acres | Percent Land Cover | Mean Percent Land Cover |
|---|---|---|---|---|
| Forest Land | Palmer Creek | 2,458 | 95% | 88% |
| | Mays Creek | 4,161 | 90% | |
| | van Buren Creek | 1,203 | 78% | |
| Shrubland | Crane Creek | 1,377 | 90% | 85% |
| | Gossage Creek | 6,457 | 83% | |
| | Blucher Creek | 4,895 | 83% | |
| Agriculture | Woolsey Creek | 3,274 | 58% | 54% |
| | Abramson Creek | 1,327 | 55% | |
| | Lambert Creek | 1,151 | 50% | |
| Developed Sewer | Piner Creek | 7,424 | 77% | 68% |
| | Copeland Creek | 1,473 | 75% | |
| | Foss Creek | 2,246 | 53% | |
| Developed Septic | Irwin Creek | 3,405 | 23% | 21% |
| | Limerick Creek | 1,528 | 20% | |
| | Turner Creek | 1,679 | 19% | |

Table 2. Statistical Comparison of Fecal Indicator Bacteria Concentrations in Runoff between Dry and Wet Weather Periods

| Fecal Indicator Bacteria | Units | Dry Period Median | Wet Period Median | Mann Whitney U Statistic | Probability | Significant Difference |
|---|---|---|---|---|---|---|
| Total Coliform | MPN/100mL | 2,382 | 29,330 | 594.5 | < 0.001 | Yes |
| *E. coli* | MPN/100mL | 97 | 1,664 | 651.0 | < 0.001 | Yes |
| *Enterococcus* | MPN/100mL | 203 | 1,773 | 205.0 | < 0.001 | Yes |
| Total Bacteroides | 16S rRNA genes/100mL | 82,022 | 1,444,232 | 48.0 | < 0.001 | Yes |
| Human-specific Bacteroides | 16S rRNA genes/100mL | 2,724 | 48,551 | 64.0 | 0.001 | Yes |
| Bovine-specific Bacteroides | 16S rRNA genes/100mL | 456 | 102,937 | 39.0 | < 0.001 | Yes |

Table 3. Statistical Comparison of Fecal Indicator Bacteria Concentrations in Runoff between Land Covers Categories

| Weather Period | Fecal Indicator Bacteria | Units | Kruskal Wallis Statistic | Probability | Significant Difference |
|---|---|---|---|---|---|
| Dry | Total Coliform | MPN/100mL | 38.606 | < 0.001 | Yes |
| | *E. coli* | MPN/100mL | 26.663 | < 0.001 | Yes |
| | *Enterococcus* | MPN/100mL | 22.848 | < 0.001 | Yes |
| | Total Bacteroides | 16S rRNA genes/100mL | 7.949 | 0.093 | No |
| | Human-specific Bacteroides | 16S rRNA genes/100mL | 7.962 | 0.093 | No |
| | Bovine-specific Bacteroides | 16S rRNA genes/100mL | 4.181 | 0.382 | No |
| | Human-specific Bacteroides | Percent Bacteroides | 0.099 | 0.999 | No |
| | Bovine-specific Bacteroides | Percent Bacteroides | 1.349 | 0.853 | No |
| Wet | Total Coliform | MPN/100mL | 22.827 | < 0.001 | Yes |
| | *E. coli* | MPN/100mL | 20.452 | < 0.001 | Yes |
| | *Enterococcus* | MPN/100mL | 27.628 | < 0.001 | Yes |
| | Total Bacteroides | 16S rRNA genes/100mL | 9.333 | 0.053 | No |
| | Human-specific Bacteroides | 16S rRNA genes/100mL | 8.675 | 0.070 | No |
| | Bovine-specific Bacteroides | 16S rRNA genes/100mL | 7.796 | 0.099 | No |
| | Human-specific Bacteroides | Percent Bacteroides | 6.243 | 0.182 | No |
| | Bovine-specific Bacteroides | Percent Bacteroides | 6.144 | 0.189 | No |

Table 4. Probabilities of a significant difference between runoff from land covers for measured total coliform concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | < 0.001 | | | | |
| | Agriculture | < 0.001 | 0.324 | | | |
| | Developed Onsite Septic | < 0.001 | 0.063 | 0.157 | | |
| | Developed Sewered | < 0.001 | 0.063 | 0.019 | 0.002 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.002 | | | | |
| | Agriculture | 0.001 | 0.435 | | | |
| | Developed Onsite Septic | < 0.001 | 0.627 | 0.316 | | |
| | Developed Sewered | < 0.001 | 0.211 | 0.033 | 0.198 | |

Table 5. Probabilities of a significant difference between runoff from land covers for measured *E. coli* bacteria concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.312 | | | | |
| | Agriculture | 0.643 | 0.087 | | | |
| | Developed Onsite Septic | < 0.001 | 0.076 | < 0.001 | | |
| | Developed Sewered | 0.002 | 0.365 | 0.006 | 0.074 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.482 | | | | |
| | Agriculture | 0.085 | 0.922 | | | |
| | Developed Onsite Septic | 0.001 | 0.030 | 0.080 | | |
| | Developed Sewered | < 0.001 | 0.003 | 0.026 | 0.681 | |

Table 6. Probabilities of a significant difference between runoff from land covers for measured *Enterococcus* bacteria concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.001 | | | | |
| | Agriculture | 0.001 | 0.152 | | | |
| | Developed Onsite Septic | < 0.001 | 0.372 | 0.012 | | |
| | Developed Sewered | 0.027 | 0.620 | 0.771 | 0.074 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.046 | | | | |
| | Agriculture | 0.002 | 0.961 | | | |
| | Developed Onsite Septic | < 0.001 | 0.010 | 0.117 | | |
| | Developed Sewered | < 0.001 | 0.001 | 0.007 | 0.455 | |

Table 7. Probabilities of a significant difference between runoff from land covers for measured Total *Bacteroides* bacteria concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.050 | | | | |
| | Agriculture | 0.025 | 0.881 | | | |
| | Developed Onsite Septic | 0.017 | 0.732 | 0.685 | | |
| | Developed Sewered | 0.050 | 0.513 | 0.456 | 0.569 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.050 | | | | |
| | Agriculture | 0.025 | 0.655 | | | |
| | Developed Onsite Septic | 0.050 | 0.513 | 0.881 | | |
| | Developed Sewered | 0.050 | 0.127 | 0.101 | 0.275 | |

Table 8. Probabilities of a significant difference between runoff from land covers for measured Human-specific *Bacteroides* bacteria concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.050 | | | | |
| | Agriculture | 0.025 | 0.655 | | | |
| | Developed Onsite Septic | 0.017 | 0.732 | 0.808 | | |
| | Developed Sewered | 0.050 | 0.513 | 0.655 | 0.425 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.180 | | | | |
| | Agriculture | 0.025 | 0.180 | | | |
| | Developed Onsite Septic | 0.050 | 0.655 | 0.297 | | |
| | Developed Sewered | 0.050 | 0.655 | 0.297 | 0.827 | |

Table 9. Probabilities of a significant difference between runoff from land covers for measured Bovine-specific *Bacteroides* bacteria concentrations

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.127 | | | | |
| | Agriculture | 0.101 | 0.655 | | | |
| | Developed Onsite Septic | 0.087 | 0.425 | 0.935 | | |
| | Developed Sewered | 0.275 | 0.513 | 0.881 | 0.909 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.050 | | | | |
| | Agriculture | 0.101 | 0.456 | | | |
| | Developed Onsite Septic | 0.050 | 0.827 | 0.881 | | |
| | Developed Sewered | 0.050 | 0.127 | 0.180 | 0.127 | |

Table 10. Probabilities of a significant difference between runoff from land covers for the percent of Human-specific *Bacteroides* bacteria

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.827 | | | | |
| | Agriculture | 0.655 | 0.655 | | | |
| | Developed Onsite Septic | 0.909 | 0.909 | 0.935 | | |
| | Developed Sewered | 0.827 | 0.827 | 0.881 | 0.909 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.180 | | | | |
| | Agriculture | 0.297 | 0.180 | | | |
| | Developed Onsite Septic | 0.127 | 0.655 | 0.180 | | |
| | Developed Sewered | 0.275 | 0.180 | 0.297 | 0.127 | |

Table 11. Probabilities of a significant difference between runoff from land covers for the percent of Bovine-specific *Bacteroides* bacteria

| Weather Period | Land Cover Category | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Forest Land | Shrubland | Agriculture | Developed Onsite Septic | Developed Sewered |
| Dry | Forest Land | | | | | |
| | Shrubland | 0.827 | | | | |
| | Agriculture | 0.655 | 0.180 | | | |
| | Developed Onsite Septic | 0.732 | 0.732 | 0.465 | | |
| | Developed Sewered | 0.513 | 0.827 | 0.655 | 0.732 | |
| Wet | Forest Land | | | | | |
| | Shrubland | 0.050 | | | | |
| | Agriculture | 0.180 | 0.881 | | | |
| | Developed Onsite Septic | 0.050 | 0.827 | 0.881 | | |
| | Developed Sewered | 0.127 | 0.275 | 0.180 | 0.275 | |

Table 12. Land Covers with a statistically significant difference in Fecal Indicator Bacteria concentrations is runoff.

| **Land Covers with Signifcant Difference** | **Fecal Indicator Bacteria** | **Weather Period** |
|---|---|---|
| Forest Land & Agriculture | Total Coliform | Dry |
| | | Wet |
| | *Enterococcus* | Dry |
| | | Wet |
| | Total *Bacteroides* | Dry |
| | | Wet |
| | Human-specfic *Bacteroides* | Dry |
| | | Wet |
| Forest Land & Developed Onsite Septic | Total Coliform | Dry |
| | | Wet |
| | *E. coli* | Dry |
| | | Wet |
| | *Enterococcus* | Dry |
| | | Wet |
| | Total *Bacteroides* | Dry |
| | | Wet |
| | Human-specfic *Bacteroides* | Dry |
| | | Wet |
| | Bovine-specfic *Bacteroides* | Wet |
| | Percent Bovine-specfic *Bacteroides* | Wet |
| Forest Land & Developed Sewered | Total Coliform | Dry |
| | | Wet |
| | *E. coli* | Dry |
| | | Wet |
| | *Enterococcus* | Dry |
| | | Wet |
| | Total *Bacteroides* | Dry |
| | | Wet |
| | Human-specfic *Bacteroides* | Dry |
| | | Wet |
| | Bovine-specfic *Bacteroides* | Wet |

Table 12 - *continued*. Land Covers with a statistically significant difference in Fecal Indicator Bacteria concentrations is runoff.

| Land Covers with Signifcant Difference | Fecal Indicator Bacteria | Weather Period |
|---|---|---|
| Forest Land & Shrubland | Total Coliform | Dry |
| | | Wet |
| | *Enterococcus* | Dry |
| | | Wet |
| | Total *Bacteroides* | Dry |
| | | Wet |
| | Human-specfic *Bacteroides* | Dry |
| | | Wet |
| | Bovine-specfic *Bacteroides* | Wet |
| Shrubland & Developed Onsite Septic | Total Coliform | Dry |
| | *E. coli* | Wet |
| | *Enterococcus* | Wet |
| Shrubland & Developed Sewered | Total Coliform | Dry |
| | *E. coli* | Wet |
| | *Enterococcus* | Wet |
| Agriculture & Developed Onsite Septic | *E. coli* | Dry |
| | *Enterococcus* | Dry |
| Agriculture & Developed Sewered | Total Coliform | Dry |
| | | Wet |
| | *E. coli* | Dry |
| | | Wet |
| | *Enterococcus* | Wet |
| Developed Onsite Septic & Developed Sewered | Total Coliform | Dry |

## FIGURES

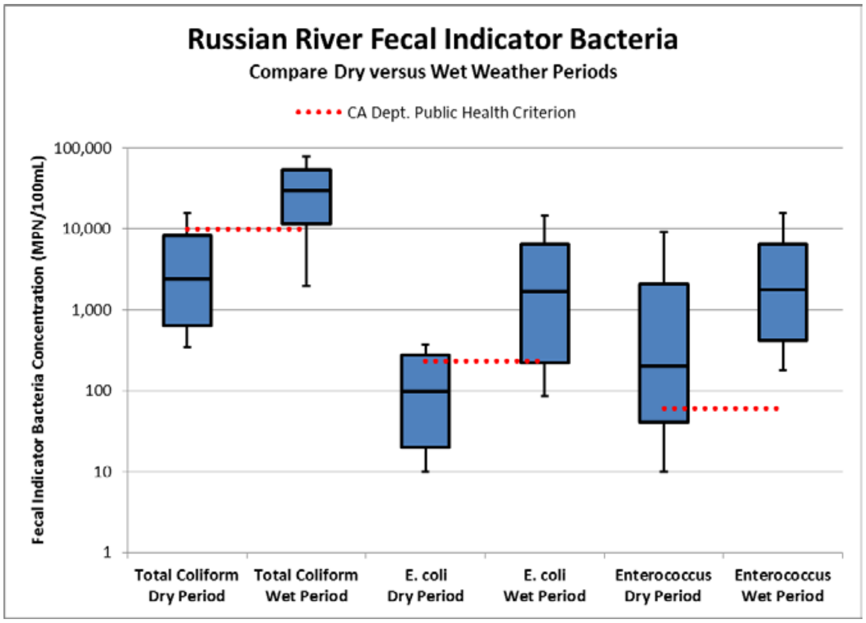


Figure 1. Fecal Indicator Bacteria Concentrations Measured in the Russian River Watershed during Both Dry and Wet Weather Periods.

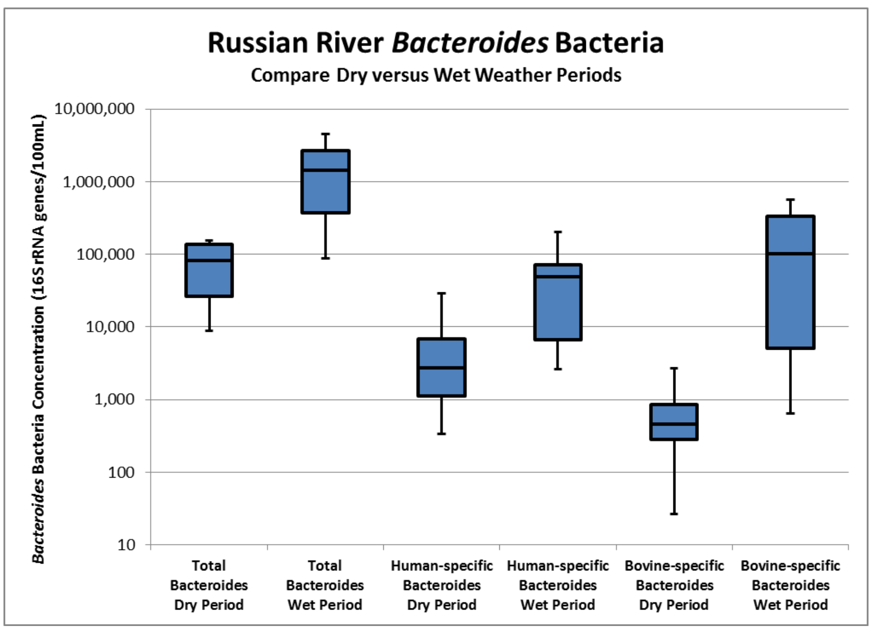


Figure 2. *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Both Dry and Wet Weather Periods.

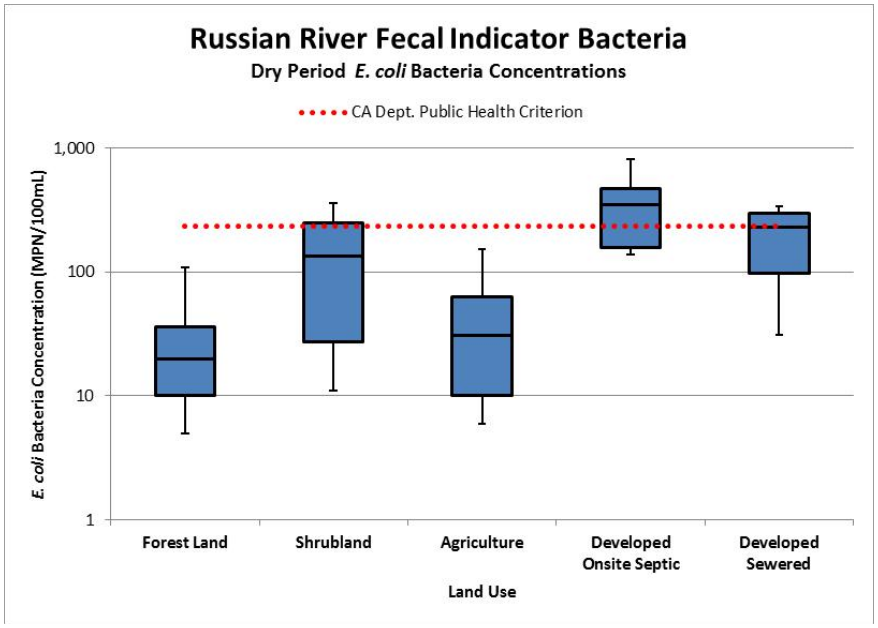


Figure 3. *E. coli* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

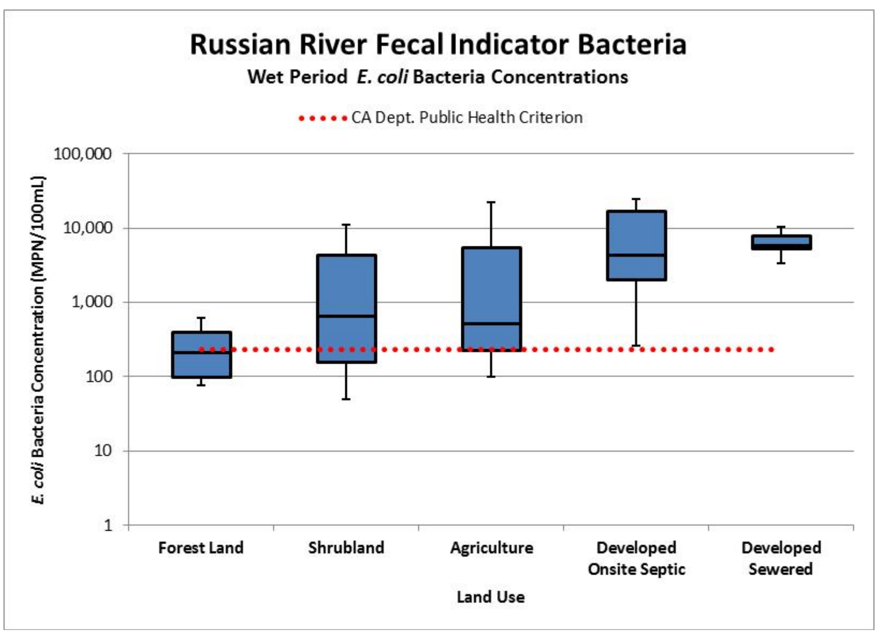


Figure 4. *E. coli* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category

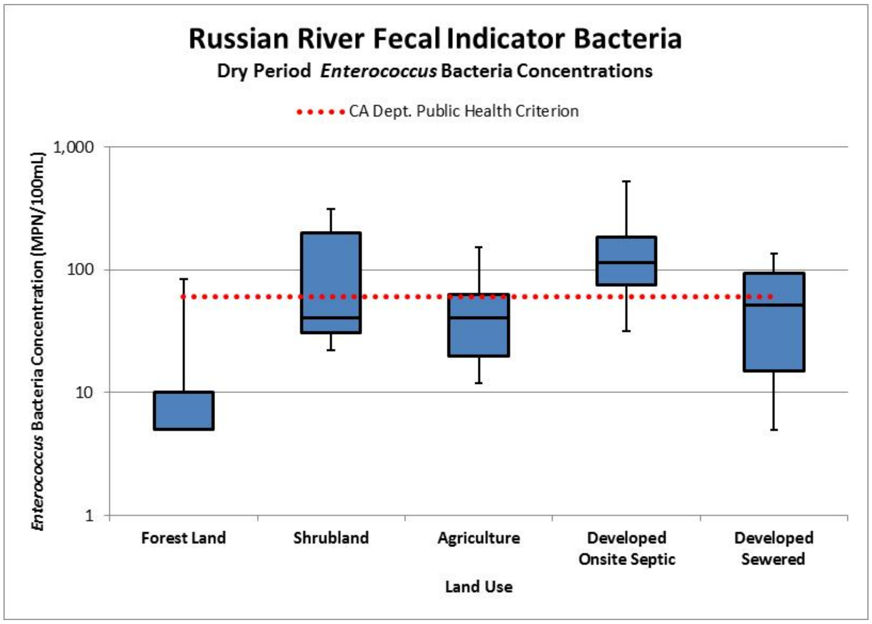


Figure 5. *Enterococcus* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

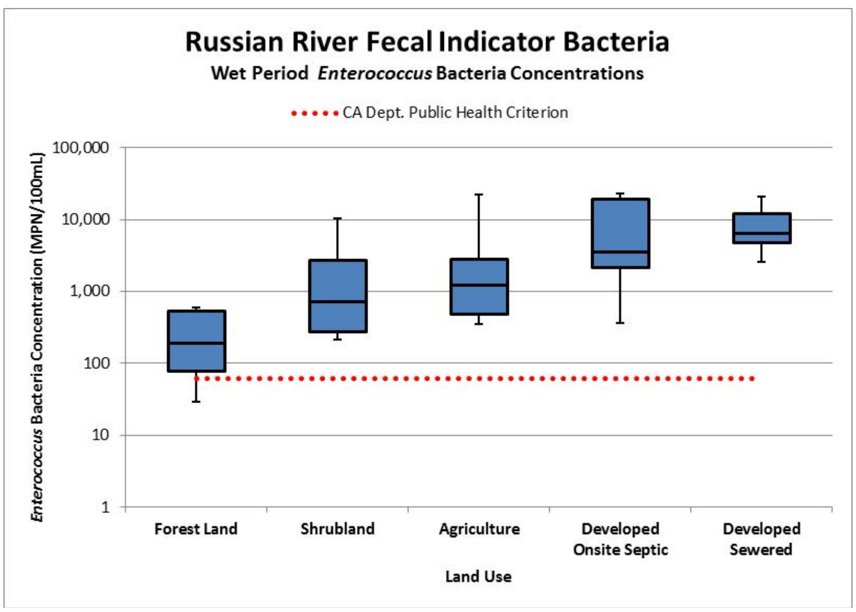


Figure 6. *Enterococcus* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

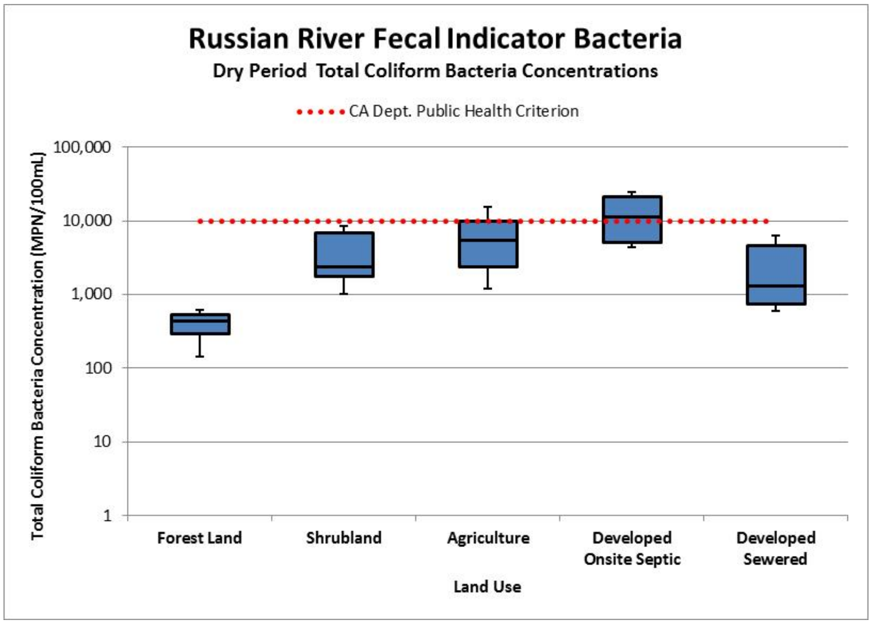


Figure 7. Total Coliform Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

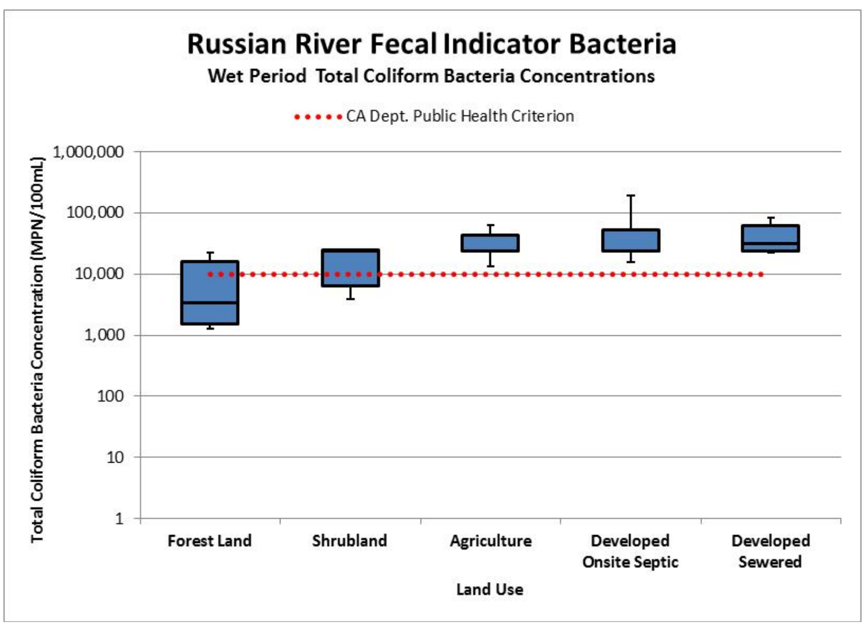


Figure 8. Total Coliform Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category

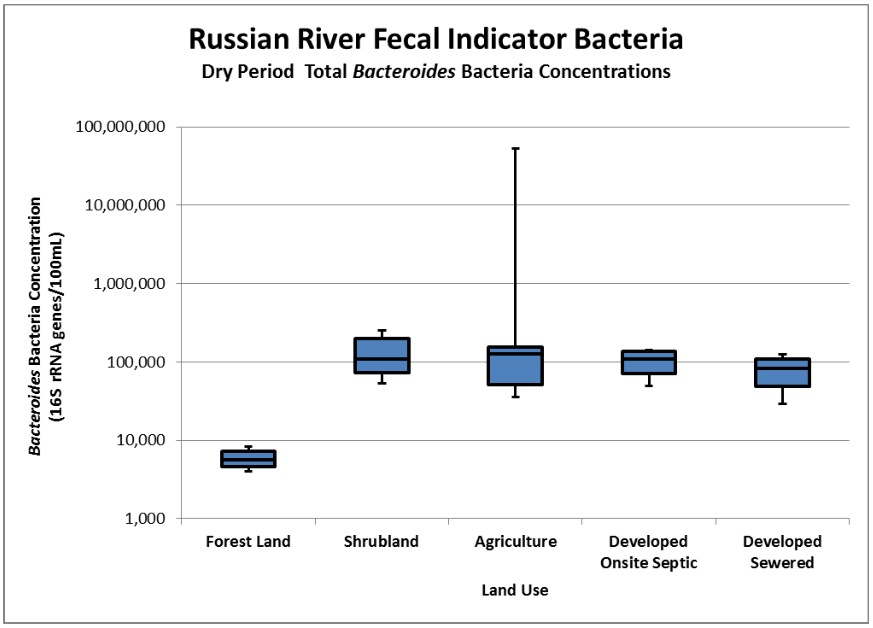


Figure 9. Total *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

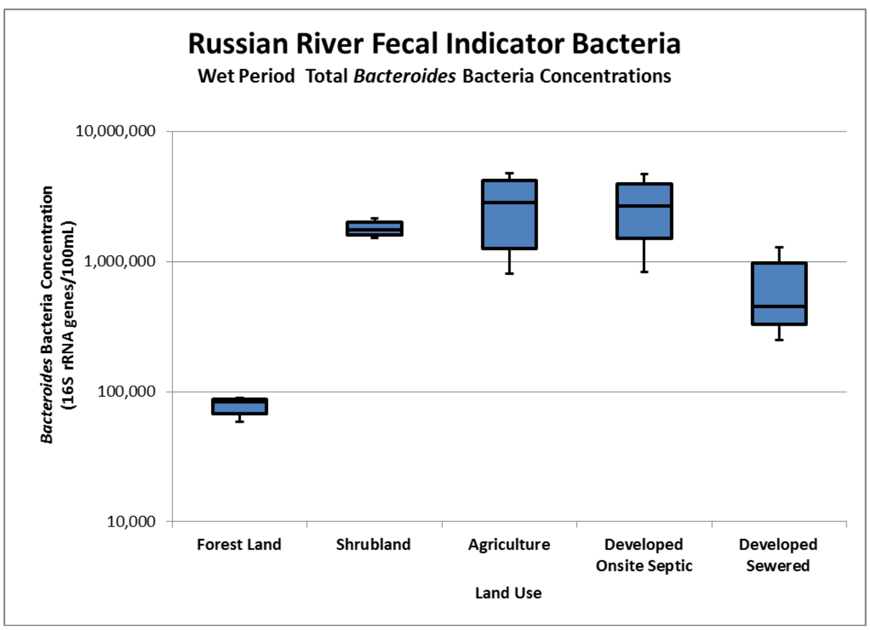


Figure 10. Total *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

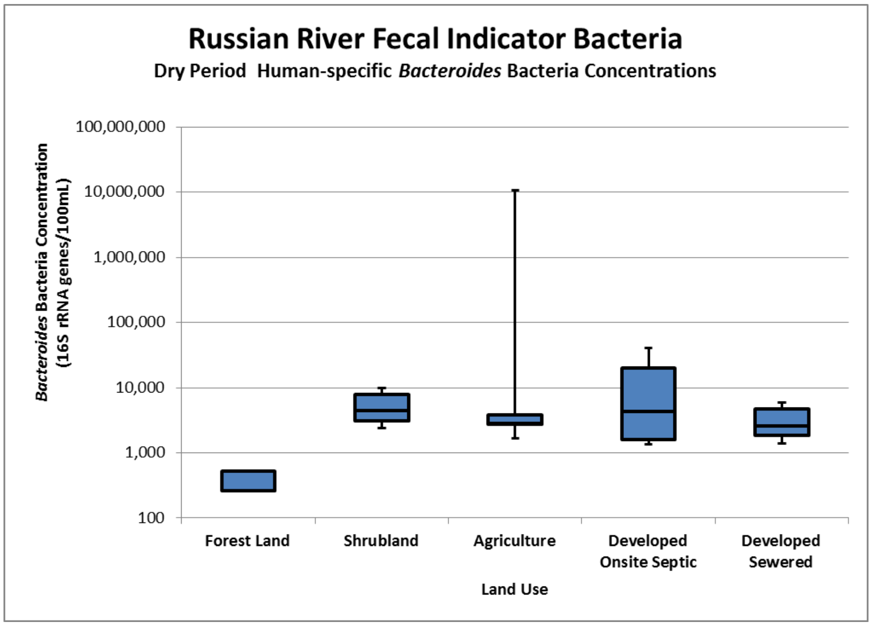


Figure 11. Human-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

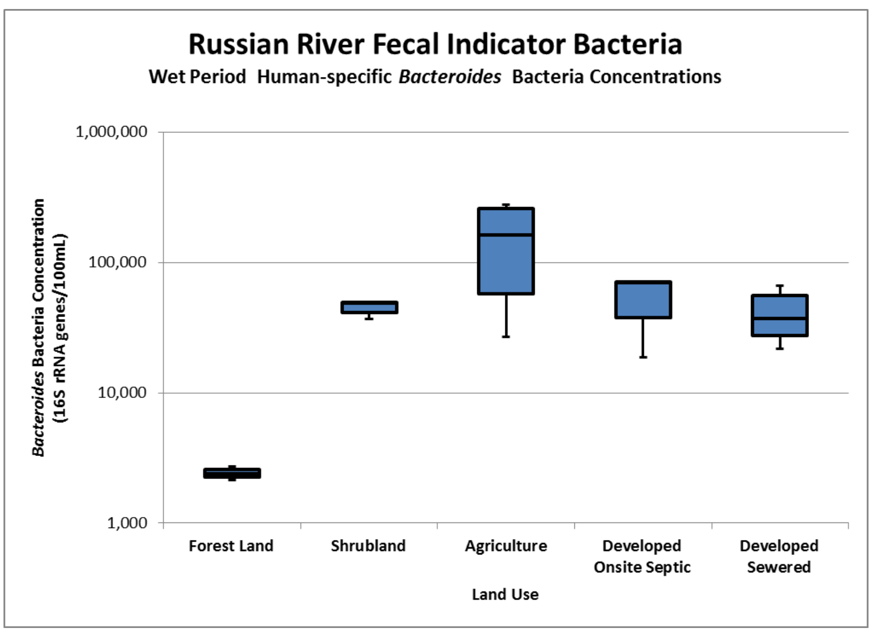


Figure 12. Human-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

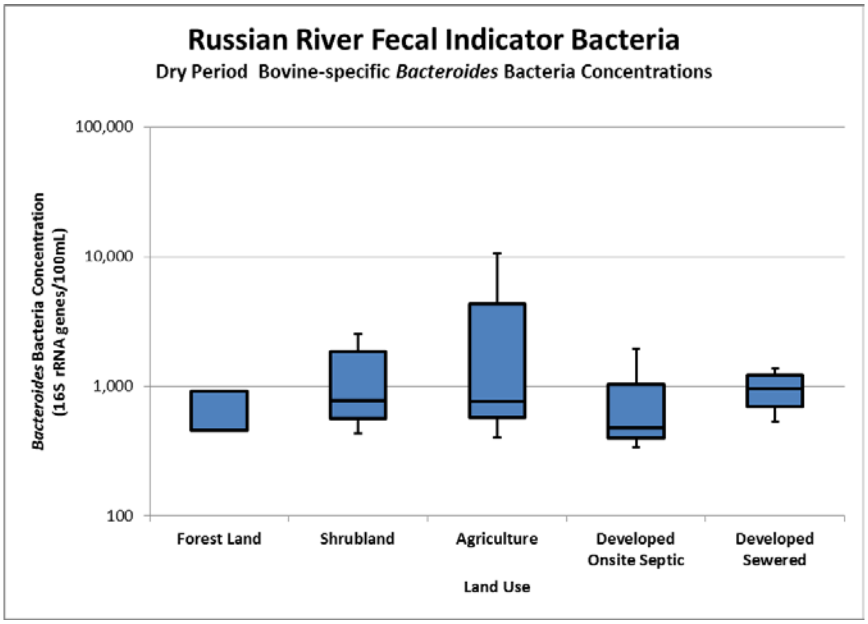


Figure 13. Bovine-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

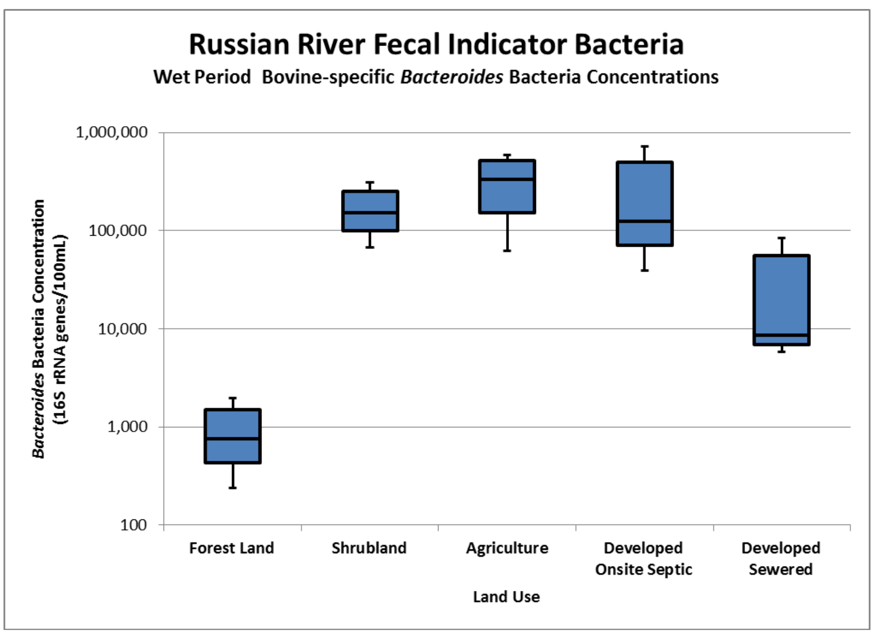


Figure 14. Bovine-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

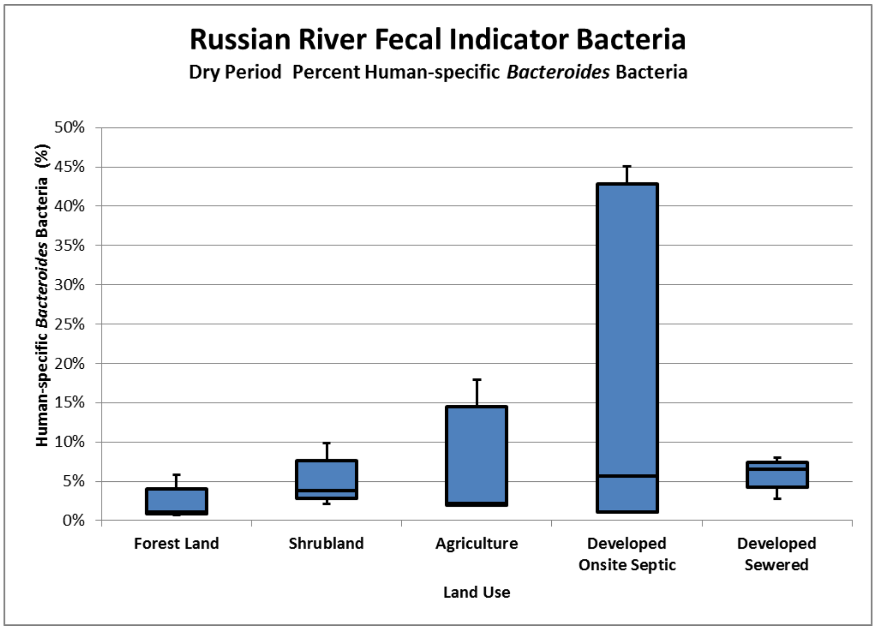


Figure 15. Percent Human-specific *Bacteroides* Bacteria Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

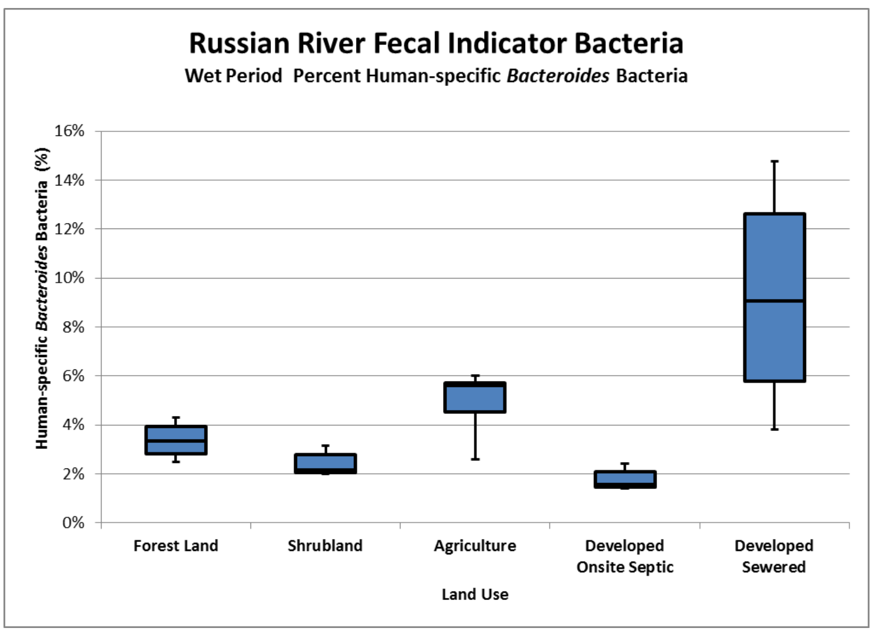


Figure 16. Percent Human-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

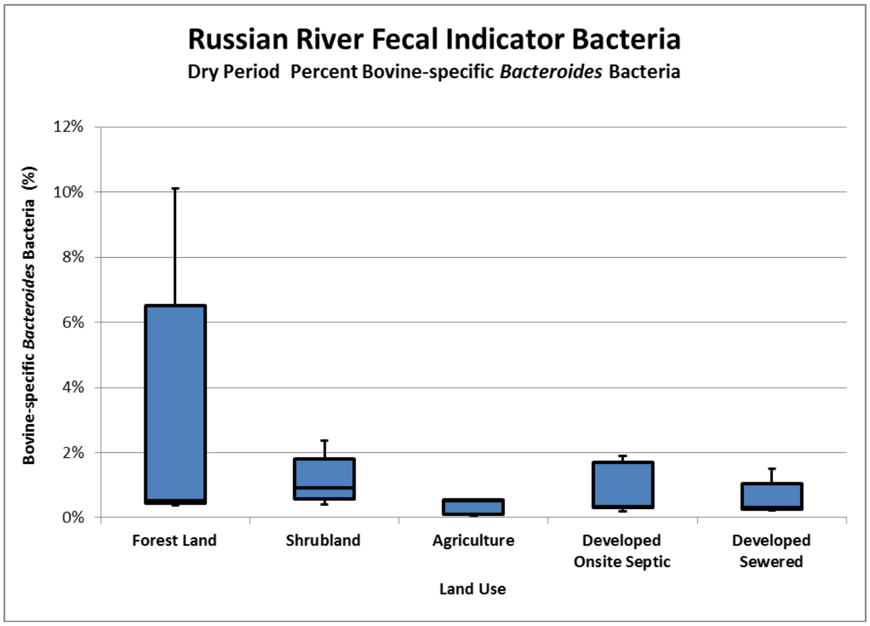


Figure 17. Percent Bovine-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Dry Periods by Land Cover Category.

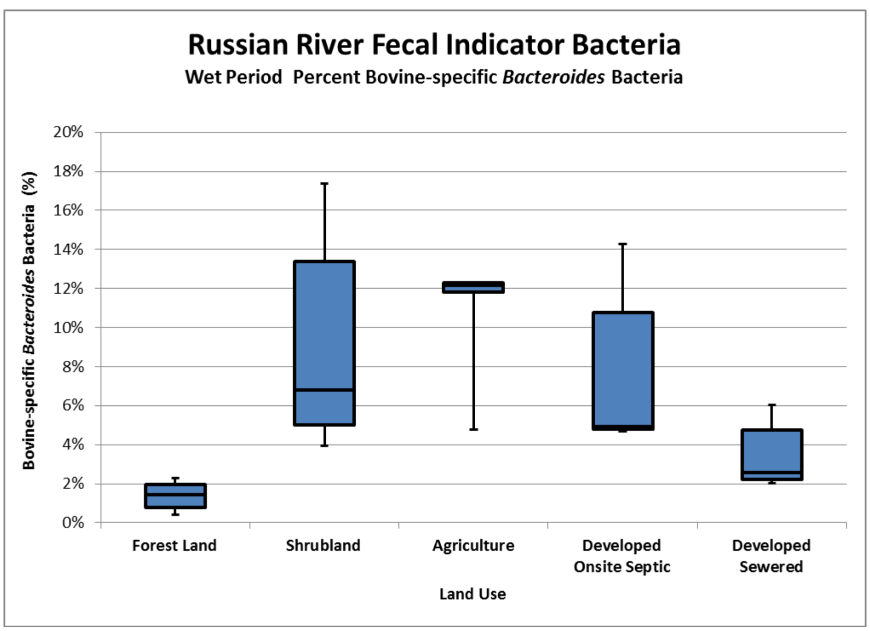


Figure 18. Percent Bovine-specific *Bacteroides* Bacteria Concentrations Measured in the Russian River Watershed during Wet Periods by Land Cover Category.

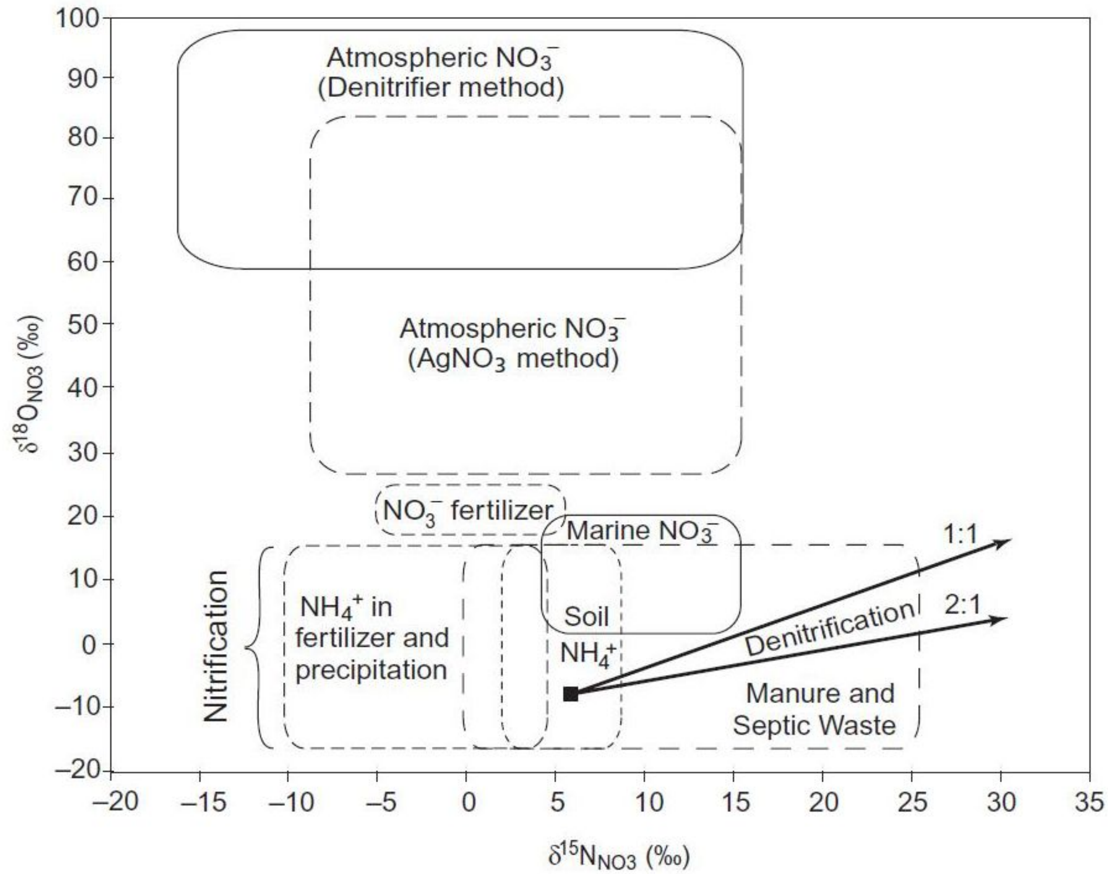


Figure 19. Typical values of δ18O and δ15N of nitrate derived from various sources (diagram from Michener and Lajtha, 2007).