CALIFORNIA
Water Boards

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North Coast Regional Water Quality Control Board

TO: File: Russian River; TMDL Development and Planning

FROM: Steve Butkus

DATE: June 4, 2014

SUBJECT: *ESCHERICHIA COLI* BACTERIA CONCENTRATION REDUCTIONS NEEDED TO MEET WATER QUALITY CRITERIA FOR DIFFERENT LAND COVER AREAS

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 water contact recreation (REC-1) and non-contact water recreation (REC-2) designated beneficial uses.

The Regional Water Board and the Sonoma County Water Agency have been collecting water samples for analysis of fecal indicator bacteria concentrations from various locations in the Russian River watershed. Recreational beneficial use criteria have been developed for measurements of bacteria concentrations to indicate a potential health risk from exposure to pathogens in surface waters. Most strains of fecal indicator bacteria (FIB) do not directly pose a health risk to swimmers (i.e., primary contact recreators), but FIB often co-occur with human pathogens and FIB concentrations are easier to measure than the actual pathogens that may pose a risk of illness. Over time, numerous measurements of FIB concentrations have been made across the Russian River watershed to assess potential impairment to REC-1 and REC-2 beneficial uses.

The purpose of this memorandum is to assess the reductions needed in fecal indicator bacteria concentrations to support REC-1 and REC-2 uses for five different land cover categories in the Russian River watershed:

1. Forest Land
2. Shrubland
3. Agriculture
4. Developed Sewered
5. Developed Onsite Septic

Recreational Beneficial Use Water Quality Criteria

The North Coast Water Quality Control Plan (Basin Plan) identifies REC-1 and REC-2 as existing beneficial uses in all surface waters of the Russian River watershed. Water Contact Recreation (REC-1) Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white-water activities, fishing, or use of natural hot springs. Non-Contact Water Recreation (REC-2) uses of water for recreational activities involving proximity to water, but not normally involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.

The Basin Plan promulgates both narrative and numeric criteria (i.e. Water Quality Objectives (WQO)) for bacteria concentrations that are protective of the REC-1 and REC -2 beneficial uses.

The Basin Plan narrative Water Quality Objective states:

> *"The bacteriological quality of waters of the North Coast Region shall not be degraded beyond natural background levels."*

The Basin Plan numeric Water Quality Objective states:

> *"In no case shall coliform concentrations in waters of the North Coast Region exceed the following: In waters designated for contact recreation (REC-1), the median fecal coliform concentration based on a minimum of not less than five samples for any 30-day period shall not exceed 50/100 ml, nor shall more than ten percent of total samples during any 30-day period exceed 400/100 ml."*

Since 2001, fecal coliform bacteria concentrations have been routinely measured in the Russian River watershed. New analytical methods were developed and approved by the U.S. Environmental Protection Agency (USEPA) that measure *Escherichia coli (E. coli)* and *Enterococcus* bacteria concentrations (IDEXX 2001). These analytical methods have been used for assessment of REC-1 in the Russian River since 2001. Therefore, the older fecal coliform bacteria concentration measurements were not assessed.

The USEPA (2012) recently published freshwater recreational beneficial use criteria based on *E. coli* bacteria concentrations (Table 1). These criteria are based on the distribution of numerous bacteria concentration measurements collected over time and are not based on measurements made from single grab samples. The criteria were published in the U.S. Federal Register for both the geometric mean and the statistical threshold (STV) values. The geometric mean criterion is compared to the logarithmic average of the bacteria concentration distribution. The STV criterion is compared to the 90th percentile of the bacteria concentration distribution. The criteria are expressed as colony forming units per

100 mL of samples. Colony forming units were assumed in this assessment to be equivalent to the most probable number derived from the new analytical methods approved by the USEPA.

Criteria were also published for two different levels of illness risk. The first level of risk (36 estimated illnesses per 1,000 recreators) is the same risk level applied with the previous recreational criteria (USEPA 1986). The USEPA (2012) also recommends more protective criteria that correspond to an illness rate of 32 estimated illnesses per 1,000 primary contact recreators to “encourage an incremental improvement in water quality.”

Bacteria Concentration Measurements

Regional Water Board staff collected 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 (NCRWQCB 2012).

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 assessments. ROS is based on the modified probability plotting (Helsel 1990). The approach fits a regression line to log transformed observation values beyond 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 was 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 distributional characteristics.

Assessment Results

Visual comparisons and statistical hypothesis tests were made between different groupings of the measured *E. coli* bacteria concentrations. Distributions of the measured *E. coli* 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. Figures 1 and 2 present the distributions of the measured *E.*

coli bacteria concentrations for each land cover category during wet and dry weather periods, respectively. Figure 3 shows the overall distribution of wet and dry samples combined. These distributions are visually compared to the USEPA (2012) geometric mean and STV criteria for the first level of risk (i.e., 36 estimated illnesses per 1,000 recreators). 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. Statistical hypothesis tests confirmed the visual observation that there was a statistically significant difference between the land covers for *E. coli* bacteria concentrations (Butkus 2013).

E. coli bacteria concentrations measured draining from the different land cover areas were assessed for REC-1 beneficial use support using the USEPA (2012) criteria. USEPA (2012) recommends a 30-day averaging period to apply the recreational criteria. The short duration was recommended to "allow for the detection of transient fluctuations in water quality in a timely manner." USEPA (2012) acknowledges that a longer duration averaging period would "improve the accuracy of the characterization of water quality." Attainment of a longer duration bacteria concentration distribution that meets REC-1 criteria will assure that any particular 30-day averaging period would also likely achieve REC-1 criteria. Therefore, all the bacteria concentration measurements collected for each land cover category were used for the assessment of REC-1 beneficial use support.

Tables 2 and 3 present the geometric means and 90th percentile values for wet and dry periods for each land cover category. Table 3 provides the same values for both wet and dry periods combined. These distribution statistics were assessed using the USEPA (2012) criteria for both levels of risk (i.e., both 36 and 32 illnesses per 1000 recreators). Tables 5 and 6 present the results of the assessment for wet and dry periods for each land cover category. The wet period runoff from all land cover categories was found to exceed REC-1 standards for *E. coli* bacteria. During the dry period, only developed areas exceeded the criteria. Table 7 provides the assessment for both wet and dry periods combined. For the combined periods, the runoff from all land cover categories was found to exceed REC-1 standards for *E. coli* bacteria.

Statistical Rollback Method

The statistical rollback method (Ott 1995) describes a way to use the statistical characteristics of a bacteria concentration distribution to estimate future concentrations after abatement processes are applied to sources. The method relies on basic dispersion and dilution assumptions and their effect on the mean and standard deviation of the bacteria concentration distribution. The statistical rollback method provides a statistical estimate of the new bacteria concentration distribution after a reduction factor is applied. With the USEPA's two-part bacteria criteria (i.e., geometric mean and STV), protection of REC-1 beneficial use will be achieved only when both criteria are met. Therefore, the percent reduction needed to meet the REC-1 beneficial use will be determined from the most restrictive of the dual bacteria concentration criteria based on the location-specific bacteria concentration distribution.

The following are the assumptions associated with the statistical rollback method (Joy 2000):

1. If Q = the concentration of a contaminant at a source, and D = the dilution-diffusion factor, and X = the concentration of the contaminant at the monitoring site, then X = Q*D.
2. Successive random dilution and diffusion of a contaminant Q in the environment often result in a lognormal distribution of the contaminant X at a distant monitoring site.
3. The coefficient of variation (CV) of Q is the same before and after applying a "rollback" (i.e., the CV in the post-control state will be the same as the CV in the pre-control state). The rollback factor = r, a reduction factor expressed as a decimal (i.e., a 70% reduction would be a rollback factor of 0.3). The random variable Q represents a pre-control source output state and rQ represents the post-control state.
4. If D remains consistent in the pre-control and post-control states (long-term hydrological and climatic conditions remain unchanged), then CV(Q)*CV(D)=CV(X), and CV(X) will be the same before and after the rollback is applied.
5. If X is multiplied by the rollback factor r, then the variance in the post-control state will be multiplied by r^2, and the post-control standard deviation will be multiplied by r.
6. If X is multiplied by the rollback factor r, the quantiles of the concentration distribution will be scaled geometrically.
7. If any random variable is multiplied by a factor r, then its expected value and standard deviation also will be multiplied by r, and its CV will be unchanged.

Since, the statistical rollback method is a parametric approach, it requires that additional assumptions are met with the bacteria concentration distribution. The data set must have independent samples, show linearity, and be distributed normally. The median bacteria concentration from replicate samples was used to address sample independence. Inadequate measurement data exist to test for serial autocorrelation, but autocorrelation is not expected between daily samples. If fact, most measurements used in the assessment were collected more than a week apart. This assures sample independence.

The linearity and normality of the bacteria concentration distributions can be confirmed through visual inspection.. Figures 4 through 13 present the bacteria concentration measurements for each land cover category. The figures plot the bacteria concentration against the standard normal variate. The standard normal variate is a normally distributed random variable with expected value 0 and variance 1. Using the standard normal variate allows the distribution to be displayed linearly. The measurements are compared to the best fit of normal and log-normal distributions derived from the measurements. For each land cover category, the bacteria concentrations fit a log-normal distribution better than a normal distribution. This assessment of the *E. coli* bacteria concentration distributions demonstrates that a logarithmic transformation of the values will provide a distribution that meets the parametric assumptions required of the statistical rollback method.

Assessment Results

Tables 8 -10 present the *E. coli* bacteria concentration reduction is needed to meet the USEPA (2012) criteria. . For each land cover category, the tables show for wet period samples, dry period samples, and both periods combined (i.e., all samples) for both levels of risk (i.e., 32 and 36 illnesses per 1000 recreators). In most cases, a larger percent reduction is needed to meet the STV criterion compared to the geometric mean criteria. For example, developed areas with sewer connection during dry period require a 9% reduction in *E. coli* concentrations to meet the geometric mean criterion. A 31% reduction is needed to meet the STV criterion. Therefore, a 31% reduction will be needed to meet both of the USEPA (2012) criteria for support of the REC-1 beneficial use.

Figures 14 through 43 demonstrate the application of the statistical rollback method with bacteria concentration measurements collected from the Russian River watershed. For each land cover category, figures are presented for wet period samples, dry period samples, and both periods combined (i.e., all samples) for both levels of risk (i.e., 32 and 36 illnesses per 1000 recreators). The figures compare the log-transformed distribution linearized by the standard normal variate using measured *E. coli* bacteria concentrations. The figures show the percent reduction in *E. coli* bacteria concentrations that will be needed to achieve both the geometric mean criterion and the STV criterion.

Findings

Based on the assessment of *E. coli* bacteria concentrations measured in the Russian River watershed and presented in this memorandum, Regional Water Board staff can make the following findings:

- *E. coli* bacteria concentrations exceeded the USEPA (2012) criteria for all land cover categories during wet periods.
- *E. coli* bacteria concentrations exceeded the USEPA (2012) criteria for developed areas both sewered and onsite septic systems during dry periods.
- *E. coli* bacteria concentrations met the USEPA (2012) criteria for forest lands, shrublands, and agricultural areas during dry periods. However, shrublands did not meet the lower risk criteria (i.e. 32 illnesses per 1000 recreators).
- For most of the locations not meeting the criteria, a larger percent reduction is needed to meet the STV criterion than is needed to meet the geometric mean criteria.

- Overall, developed areas (both sewered and with onsite septic systems) require a 98% reduction in E. coli bacteria concentrations to meet the criteria.
- Shrublands areas require a 96% reduction in E. coli bacteria concentrations to meet the criteria.
- Agricultural areas require a 87% reduction in E. coli bacteria concentrations to meet the criteria.
- Forested areas require a 33% reduction in E. coli bacteria concentrations to meet the criteria.

CITATIONS

Butkus, S. 2013. Assessment of Fecal Indicator Bacteria Concentrations Measured Draining Areas with Different Land Covers. Memorandum to the Russian River TMDL File dated January 18, 2013. North Coast Regional Water Quality Control Board, Santa Rosa, CA.

Helsel, D.R. 1990. Less Than Obvious: Statistical Treatment of Data Below the Detection Limit. *Environmental Science and Technology* 24(12): 1766-1774.

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Ott, W., 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

USEPA 1986. Ambient Water Quality Criteria for Bacteria – 1986. Publication No. EPA440/5-84-002. U.S. Environmental Protection Agency: Washington, DC.

USEPA 2012. Recreational Water Quality Criteria. Publication No. EPA 820-F-12-058. U.S. Environmental Protection Agency, Washington, DC.

TABLES

Table 1. Recreational water quality criteria (USEPA 2012)

Criteria Elements	**Recommendation 1** Estimated Illness Rate 36 per 1,000 recreators		**Recommendation 2** Estimated Illness Rate 32 per 1,000 recreators	
Indicator Bacteria	Geometric Mean (cfu/100mL)	Statistical Threshold Value (cfu/100mL)	Geometric Mean (cfu/100mL)	Statistical Threshold Value (cfu/100mL)
E. coli	126	410	100	320

Table 2. Distribution statistics for wet period *E. coli* bacteria concentration measurements from samples collected from runoff draining different land cover areas

Land Cover Category	**Geometric Mean (MPN/100mL)**	**90th Percentile (MPN/100mL)**
Forest Land	201	610
Shrubland	1,081	11,405
Agriculture	740	6,681
Developed Sewer	5,372	9,447
Developed Onsite Septic	3,665	24,196

Table 3. Distribution statistics for dry period *E. coli* bacteria concentration measurements from samples collected from runoff draining different land cover areas

Land Cover Category	Geometric Mean (MPN/100mL)	90^{th} Percentile (MPN/100mL)
Forest Land	21	116
Shrubland	95	369
Agriculture	29	153
Developed Sewer	138	341
Developed Onsite Septic	364	812

Table 4. Distribution statistics for all *E. coli* bacteria concentration measurements from samples collected from runoff draining different land cover areas

Land Cover Category	Geometric Mean (MPN/100mL)	90^{th} Percentile (MPN/100mL)
Forest Land	65	475
Shrubland	386	8,665
Agriculture	136	5,962
Developed Sewer	933	7,985
Developed Onsite Septic	1,262	20,763

Table 5. Assessment of wet period *E. coli* bacteria concentration measurements using USEPA (2012) criteria for REC-1 beneficial use.

Land Cover Category	**Does the Distribution Exceed the Criteria?**					
	Illness rate = 36/1000 recreators			**Illness rate = 32/1000 recreators**		
	Geomean <= 126	**STV <= 410**	**REC-1**	**Geomean <= 100**	**STV <= 320**	**REC-1**
Forest Land	Yes	Yes	Yes	Yes	Yes	Yes
Shrubland	Yes	Yes	Yes	Yes	Yes	Yes
Agriculture	Yes	Yes	Yes	Yes	Yes	Yes
Developed Sewer	Yes	Yes	Yes	Yes	Yes	Yes
Developed Onsite Septic	Yes	Yes	Yes	Yes	Yes	Yes

Table 6. Assessment of dry period *E. coli* bacteria concentration measurements using USEPA (2012) criteria for REC-1 beneficial use.

Land Cover Category	**Does the Distribution Exceed the Criteria?**					
	Illness rate = 36/1000 recreators			**Illness rate = 32/1000 recreators**		
	Geomean <= 126	**STV <= 410**	**REC-1**	**Geomean <= 100**	**STV <= 320**	**REC-1**
Forest Land	No	No	No	No	No	No
Shrubland	No	No	No	No	Yes	Yes
Agriculture	No	No	No	No	No	No
Developed Sewer	Yes	No	Yes	Yes	Yes	Yes
Developed Onsite Septic	Yes	Yes	Yes	Yes	Yes	Yes

Table 7. Assessment of all *E. coli* bacteria concentration measurements using USEPA (2012) criteria for REC-1 beneficial use.

Land Cover Category	Does the Distribution Exceed the Criteria?					
	Illness rate = 36/1000 recreators			Illness rate = 32/1000 recreators		
	Geomean <= 126	STV <= 410	REC-1	Geomean <= 100	STV <= 320	REC-1
Forest Land	No	Yes	Yes	Yes	Yes	Yes
Shrubland	Yes	Yes	Yes	Yes	Yes	Yes
Agriculture	Yes	Yes	Yes	Yes	Yes	Yes
Developed Sewer	Yes	Yes	Yes	Yes	Yes	Yes
Developed Onsite Septic	Yes	Yes	Yes	Yes	Yes	Yes

Table 8. Percent reductions needed to meet wet period *E. coli* bacteria concentration criteria

Land Cover Category	Percent Reduction needed to Meet Criteria					
	Illness rate = 36/1000 recreators			Illness rate = 32/1000 recreators		
	Geomean <= 126	STV <= 410	REC-1	Geomean <= 100	STV <= 320	REC-1
Forest Land	45	27	45	56	43	56
Shrubland	88	98	98	91	98	98
Agriculture	83	95	95	86	96	96
Developed Sewer	98	97	98	98	98	98
Developed Onsite Septic	97	99	99	97	99	99

Table 9. Percent reductions needed to meet dry period *E. coli* bacteria concentration criteria

Land Cover Category	**Percent Reduction needed to Meet Criteria**					
	Illness rate = 36/1000 recreators			**Illness rate = 32/1000 recreators**		
	Geomean <= 126	**STV <= 410**	**REC-1**	**Geomean <= 100**	**STV <= 320**	**REC-1**
Forest Land	0	0	0	0	0	0
Shrubland	0	45	45	0	57	57
Agriculture	0	0	0	0	0	0
Developed Sewer	9	31	31	28	46	46
Developed Onsite Septic	65	77	77	72	82	82

Table 10. Percent reductions needed to meet all *E. coli* bacteria concentration criteria

Land Cover Category	**Percent Reduction needed to Meet Criteria**					
	Illness rate = 36/1000 recreators			**Illness rate = 32/1000 recreators**		
	Geomean <= 126	**STV <= 410**	**REC-1**	**Geomean <= 100**	**STV <= 320**	**REC-1**
Forest Land	0	14	14	0	33	33
Shrubland	67	94	94	74	96	96
Agriculture	7	83	83	27	87	87
Developed Sewer	86	97	97	89	98	98
Developed Onsite Septic	90	98	98	92	98	98

FIGURES

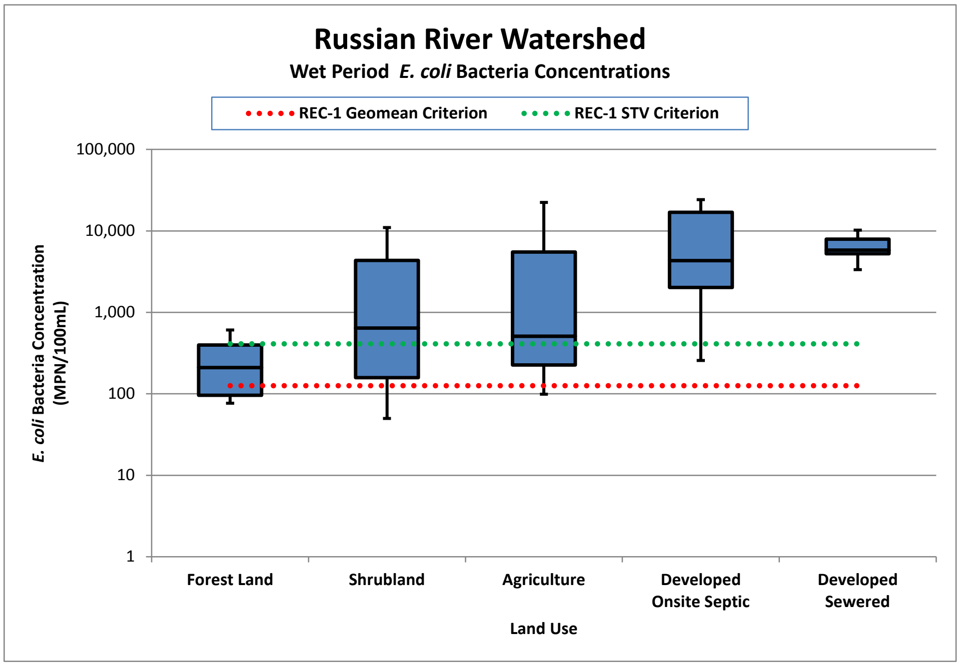

Figure 1. Distribution of wet period *E. coli* bacteria concentrations between land cover categories

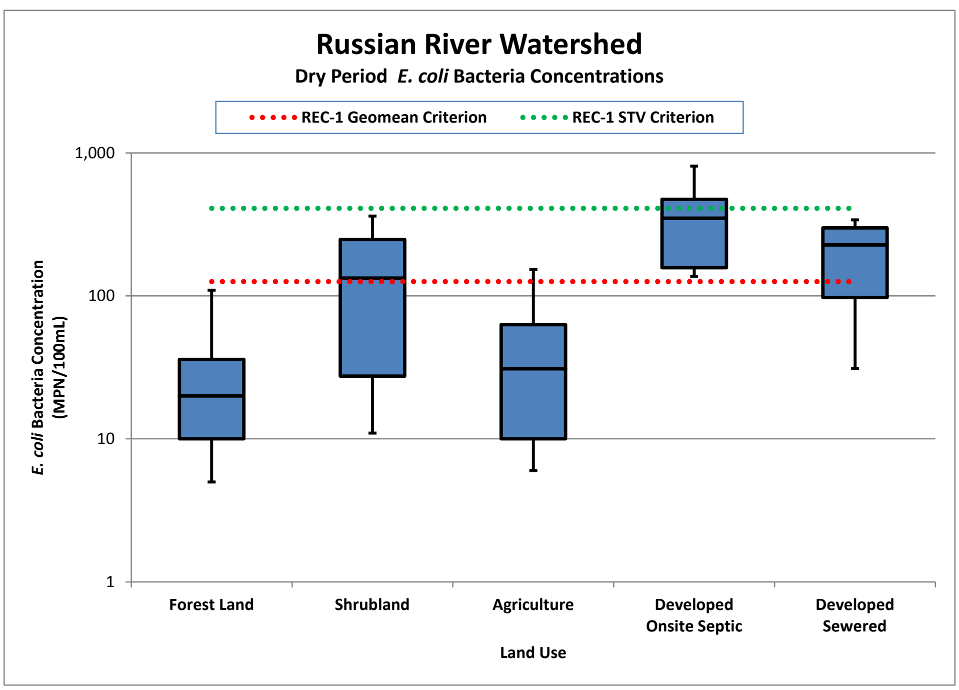

Figure 2. Distribution of dry period *E. coli* bacteria concentrations between land cover categories

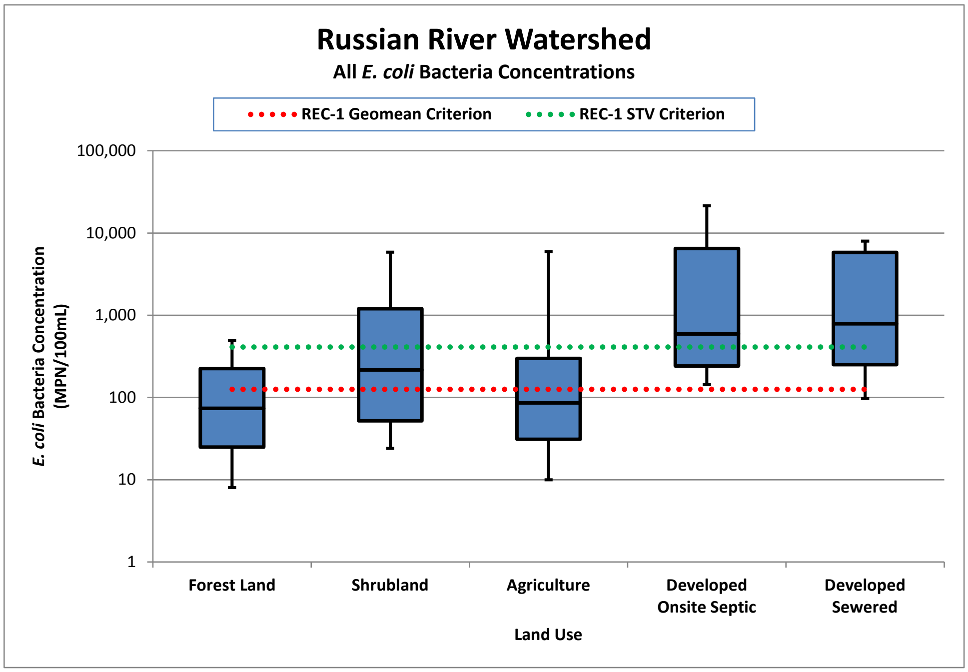

Figure 3. Distribution of all *E. coli* bacteria concentrations between land cover categories

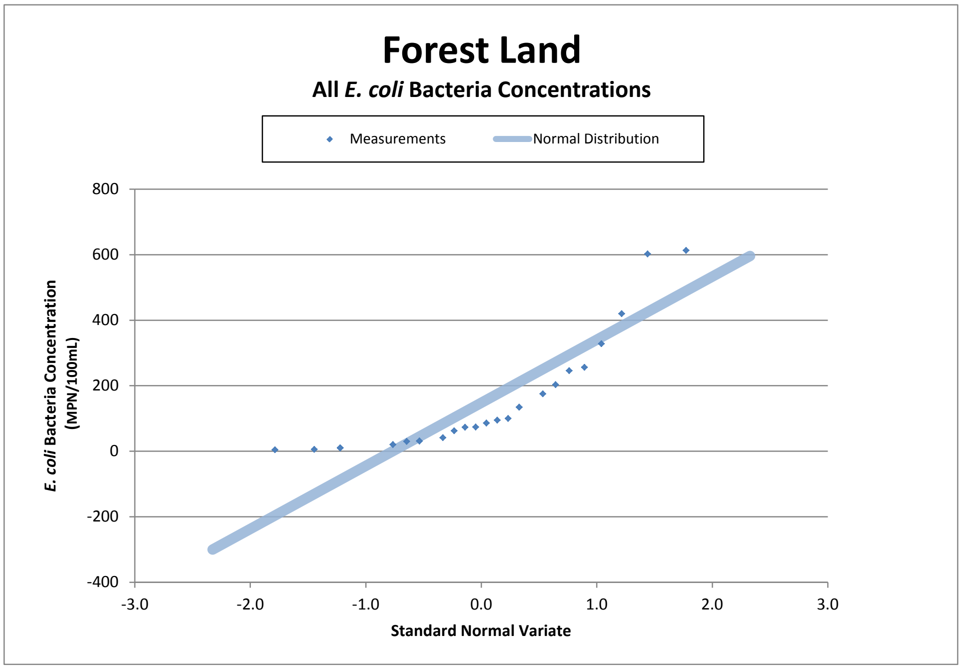

Figure 4. Normal distribution compared to *E. coli* bacteria concentration measurements collected from forested areas in the Russian River

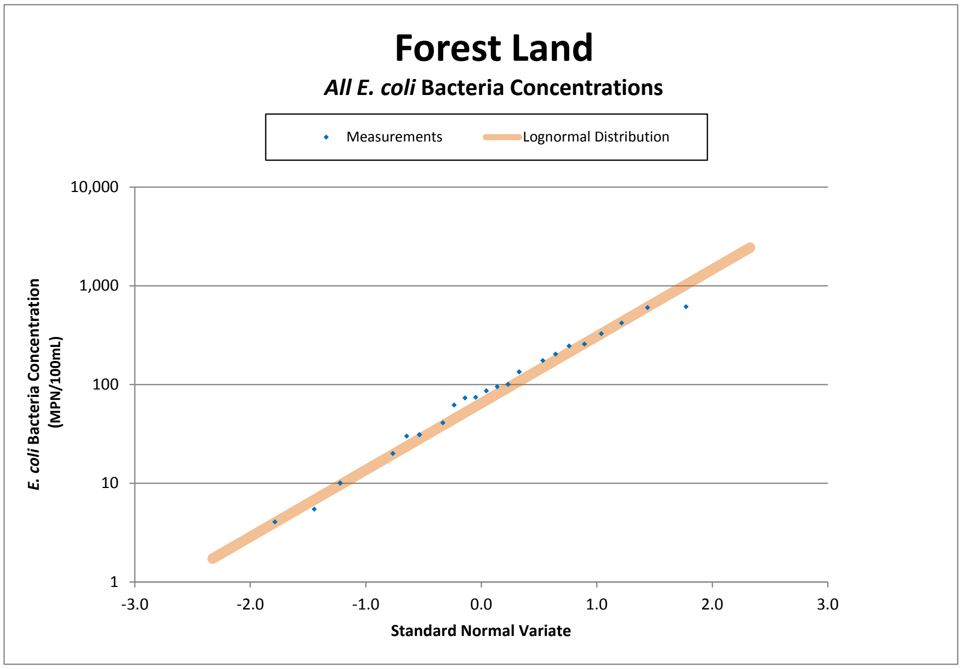

Figure 5. Log-normal distribution compared to *E. coli* bacteria concentration measurements collected from forested areas in the Russian River

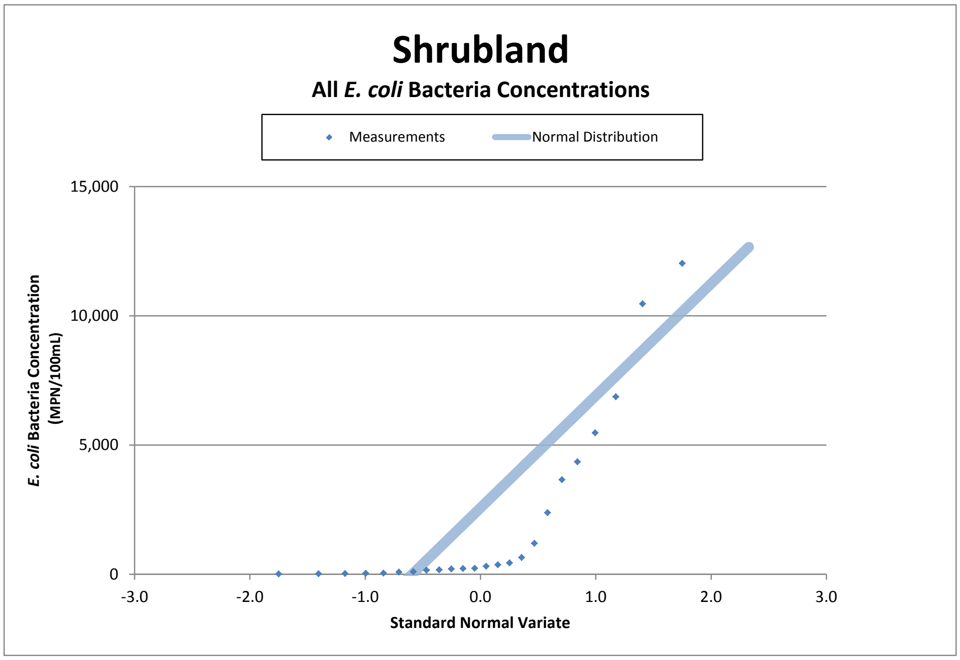

Figure 6. Normal distribution compared to *E. coli* bacteria concentration measurements collected from shrubland areas in the Russian River

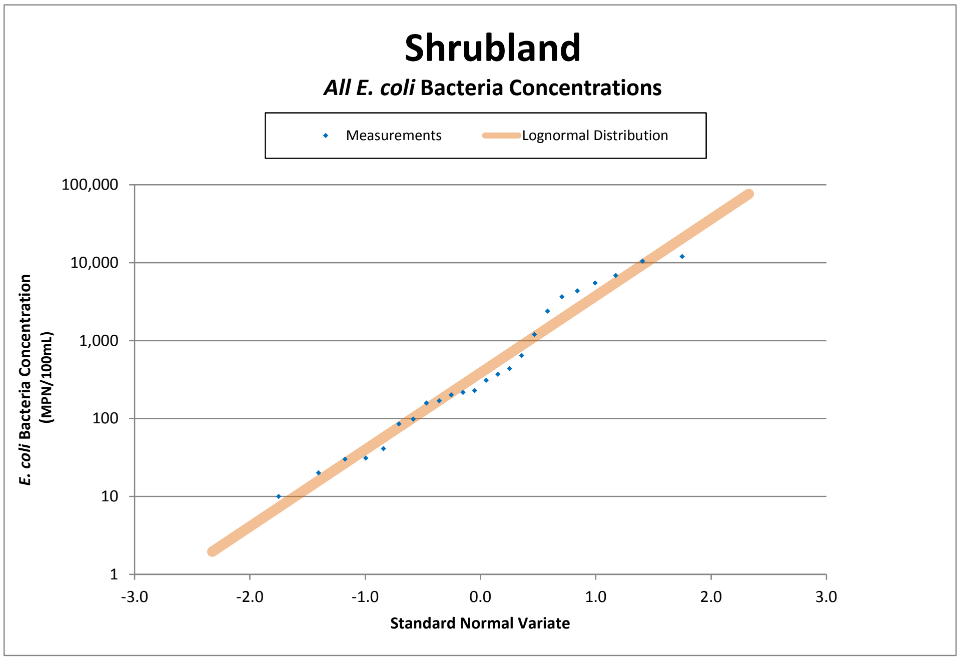

Figure 7. Log-normal distribution compared to *E. coli* bacteria concentration measurements collected from shrubland areas in the Russian River

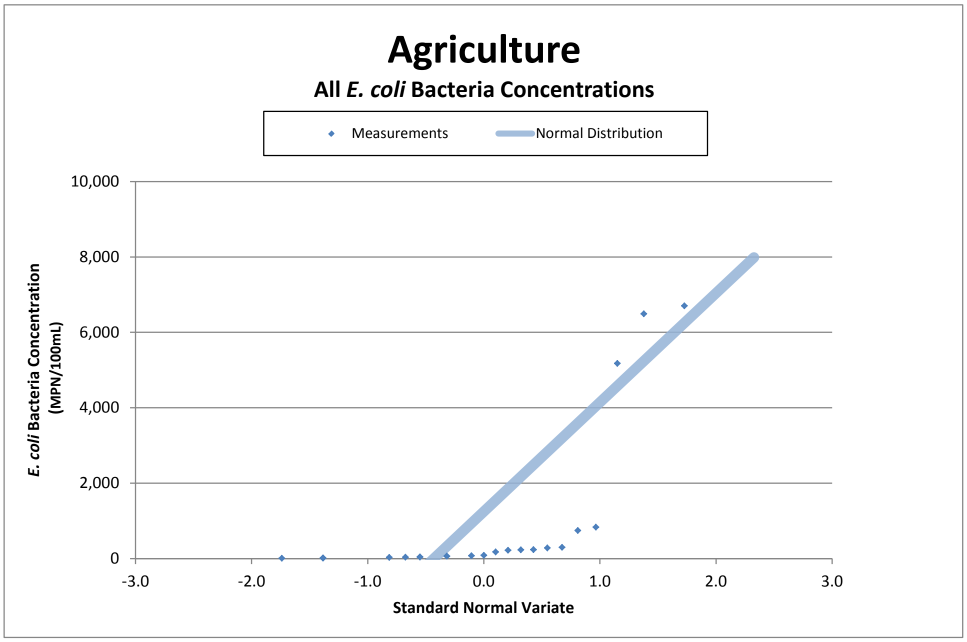

Figure 8. Normal distribution compared to *E. coli* bacteria concentration measurements collected from agricultural areas in the Russian River

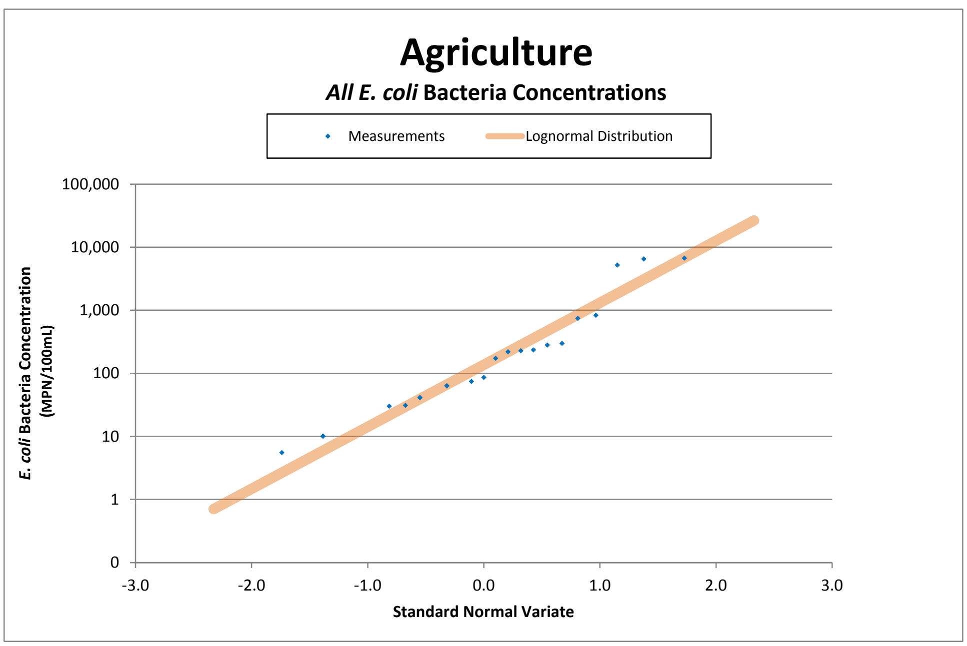

Figure 9. Log-normal distribution compared to *E. coli* bacteria concentration measurements collected from agricultural areas in the Russian River

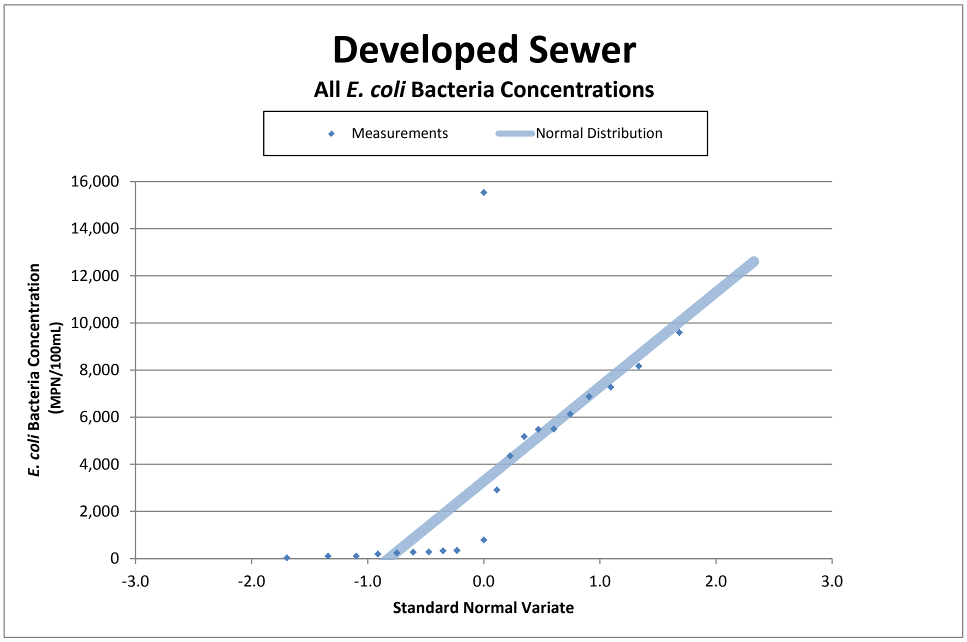

Figure 10. Normal distribution compared to *E. coli* bacteria concentration measurements collected from developed areas with sewer connections in the Russian River

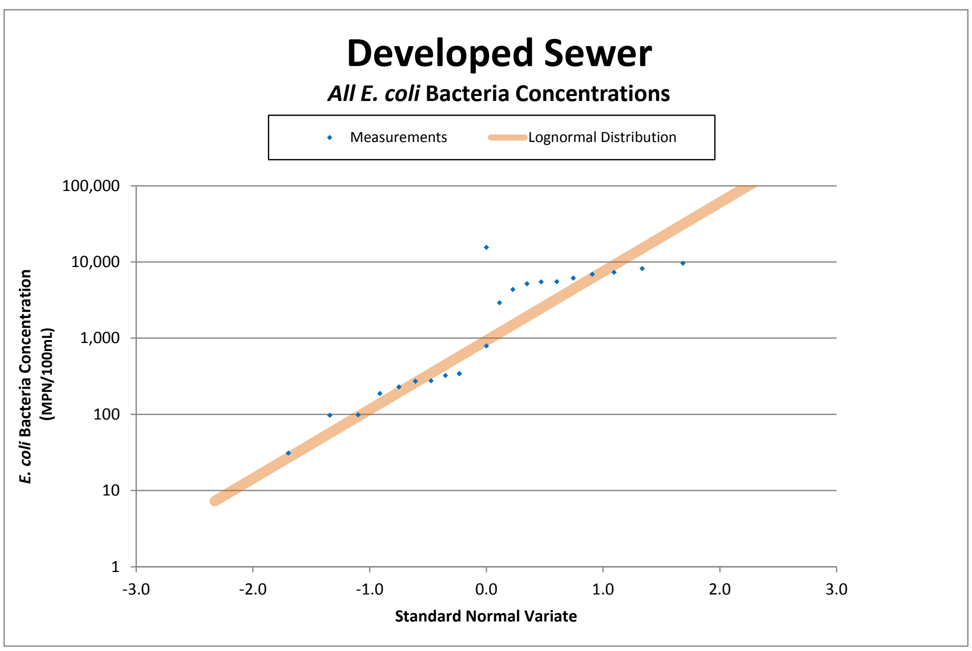

Figure 11. Log-normal distribution compared to *E. coli* bacteria concentration measurements collected in developed areas with sewer connections in the Russian River

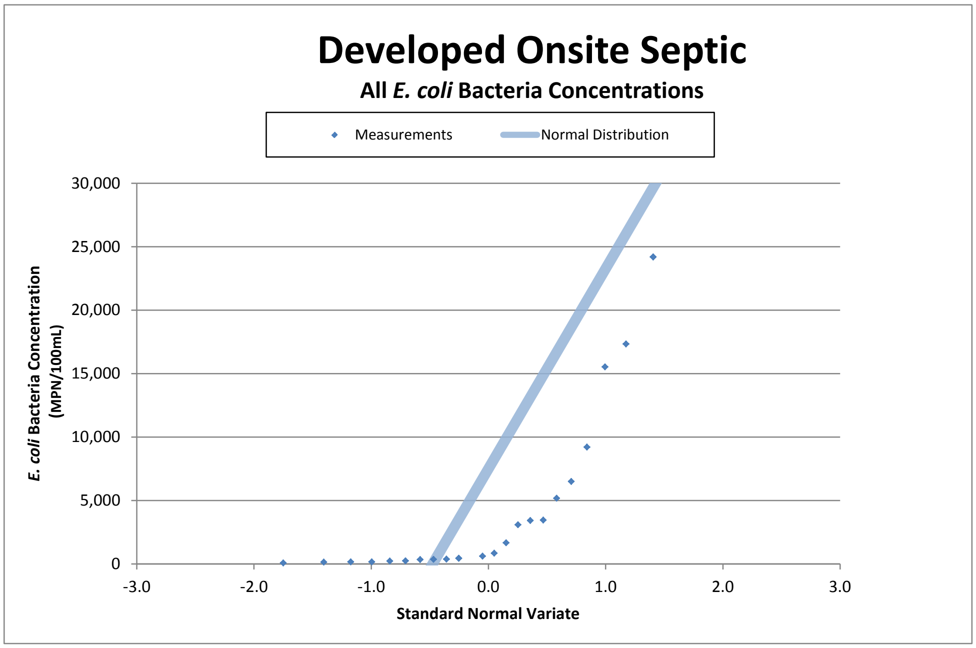

Figure 12. Normal distribution compared to *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems in the Russian River

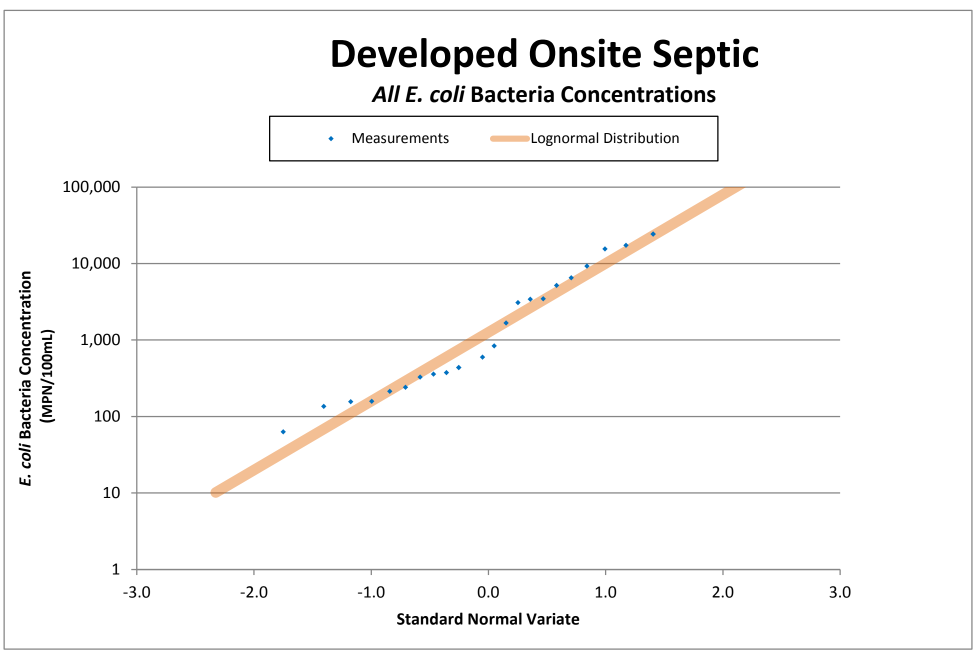

Figure 13. Log-normal distribution compared to *E. coli* bacteria concentration measurements collected in developed areas with onsite septic systems in the Russian River

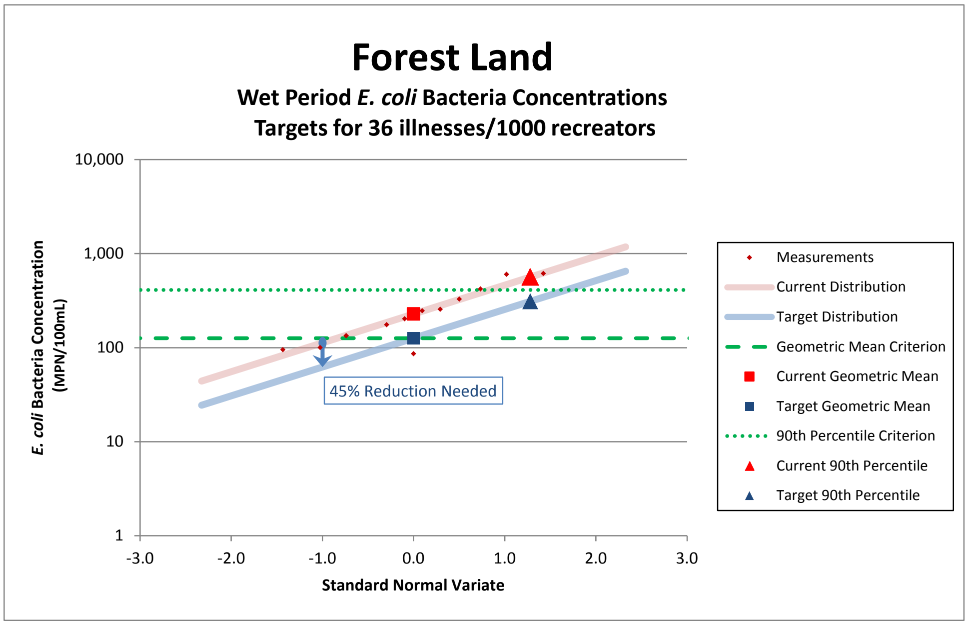

Figure 14. Comparison of *E. coli* bacteria concentration measurements collected from forested areas during wet periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

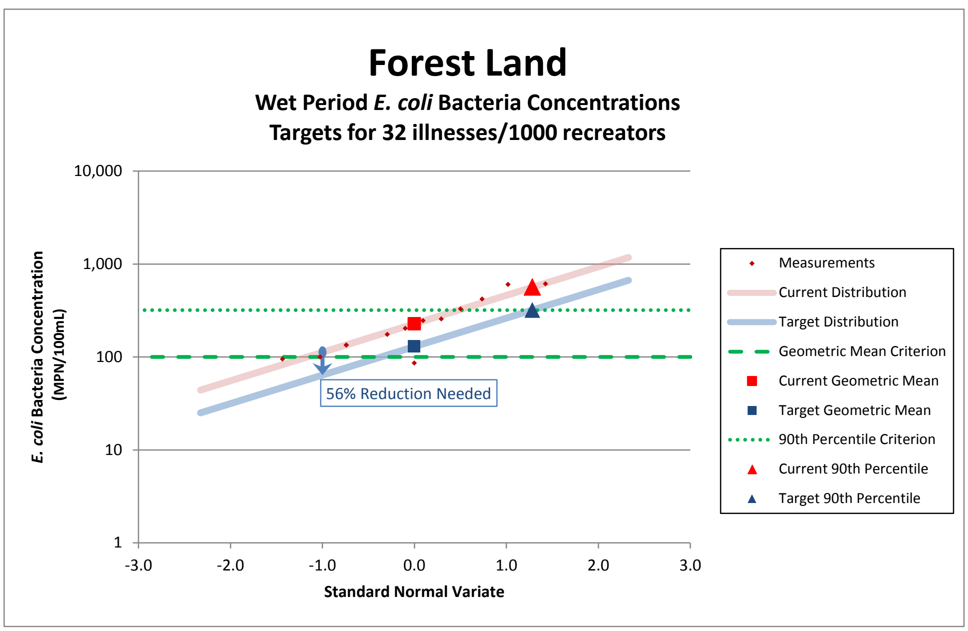

Figure 15. Comparison of *E. coli* bacteria concentration measurements collected from forested areas during wet periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

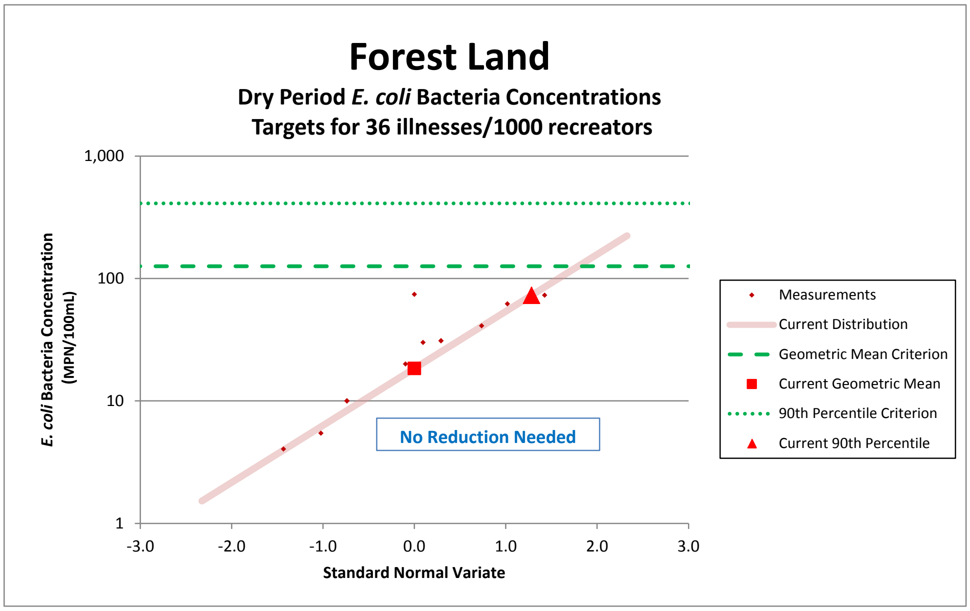

Figure 16. Comparison of *E. coli* bacteria concentration measurements collected from forested areas during dry periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators. Target is currently being met and no reduction in bacteria concentration is needed.

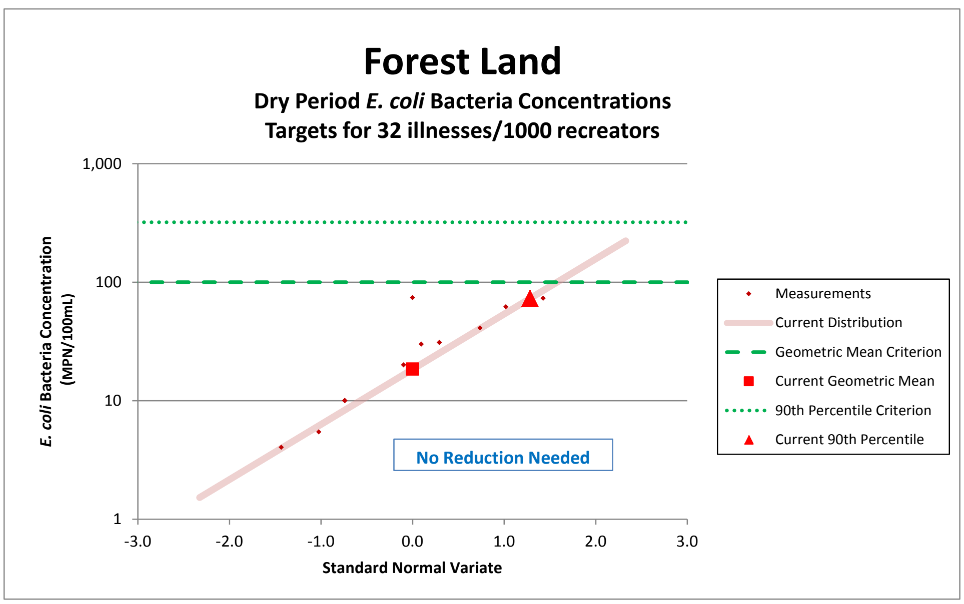

Figure 17. Comparison of *E. coli* bacteria concentration measurements collected from forested areas during dry periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators. Target is currently being met and no reduction in bacteria concentration is needed.

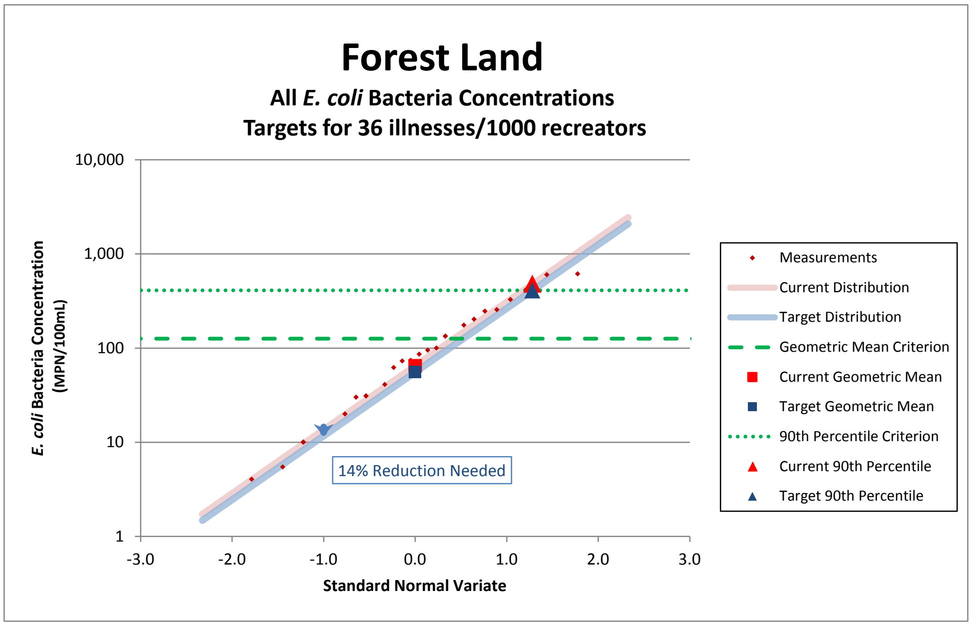

Figure 18. Comparison of all *E. coli* bacteria concentration measurements collected from forested areas in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

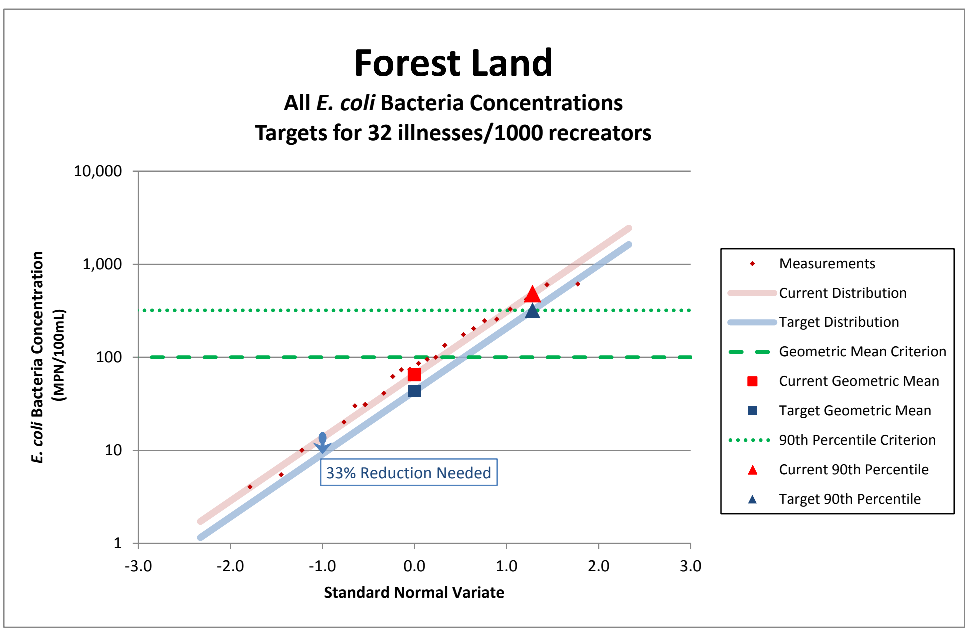

Figure 19. Comparison of all *E. coli* bacteria concentration measurements collected from forested areas in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

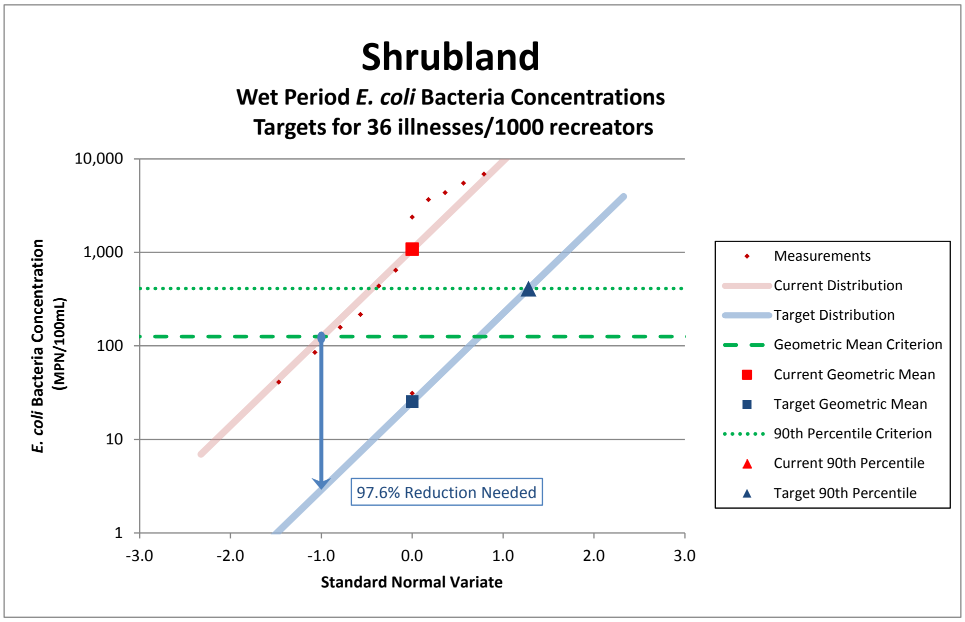

Figure 20. Comparison of *E. coli* bacteria concentration measurements collected from shrubland areas during wet periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

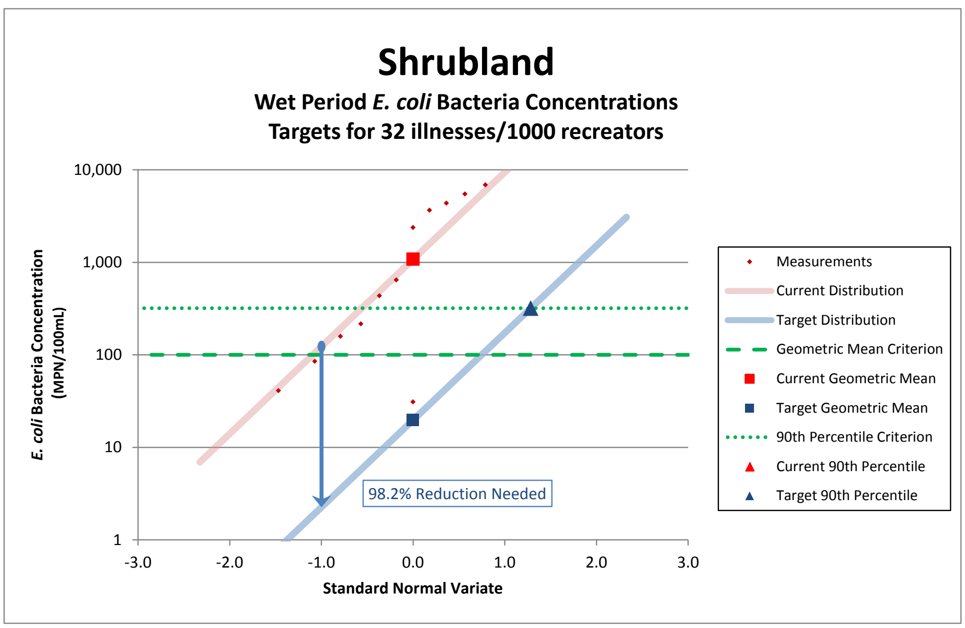

Figure 21. Comparison of *E. coli* bacteria concentration measurements collected from shrubland areas during wet periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

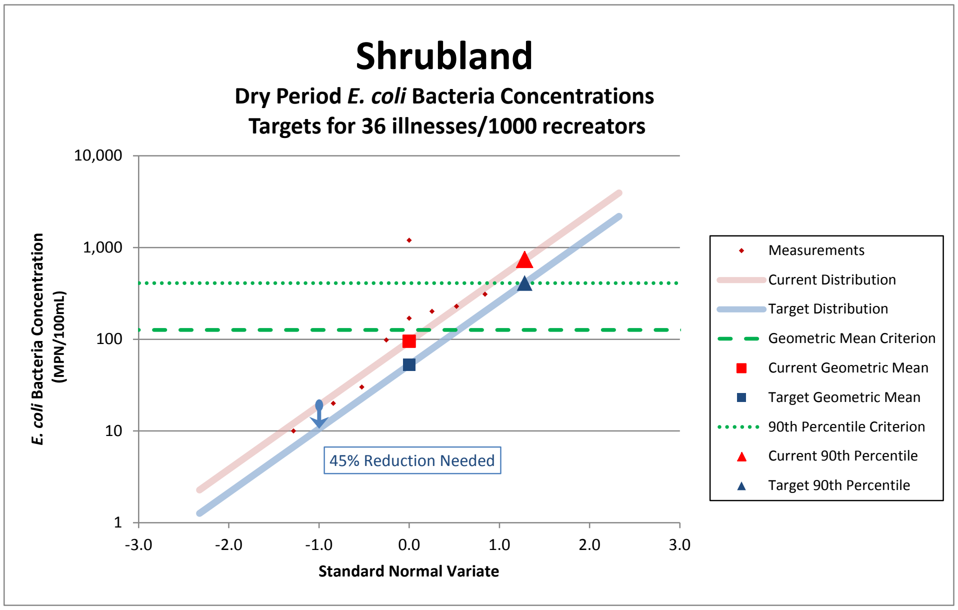

Figure 22. Comparison of *E. coli* bacteria concentration measurements collected from shrubland areas during dry periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

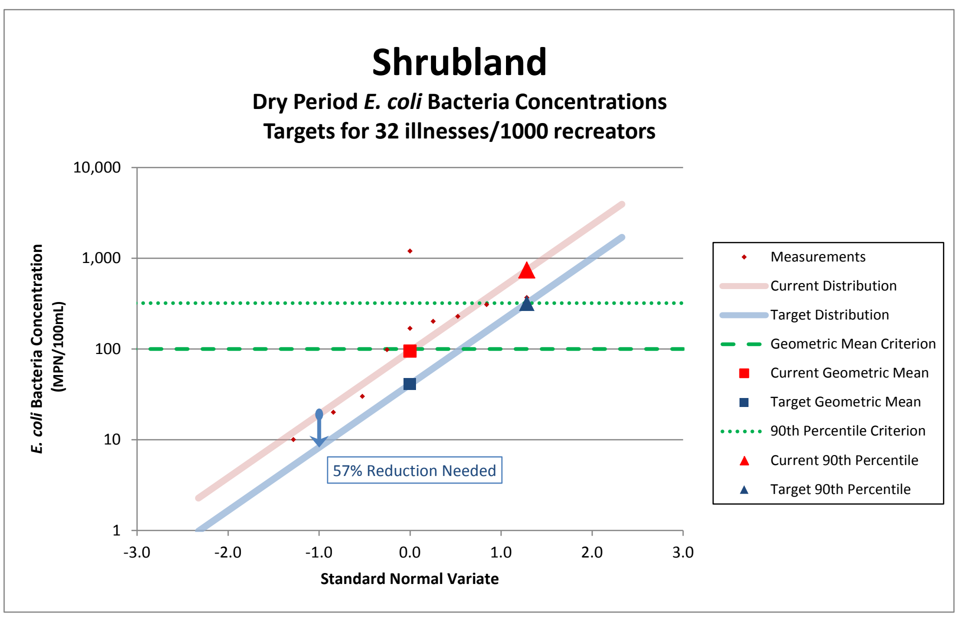

Figure 23. Comparison of *E. coli* bacteria concentration measurements collected from shrubland areas during dry periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

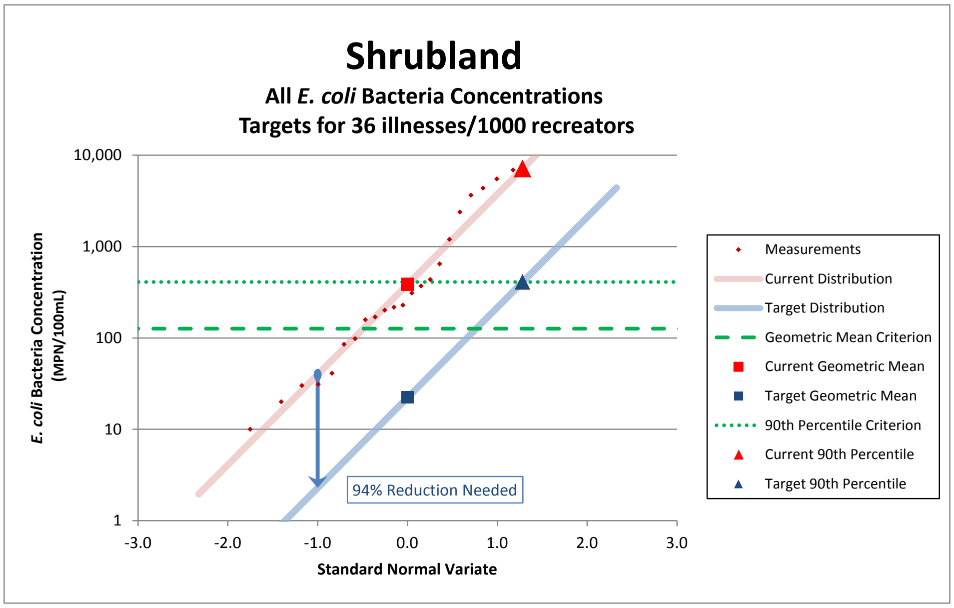

Figure 24. Comparison of all *E. coli* bacteria concentration measurements collected from shrubland areas in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

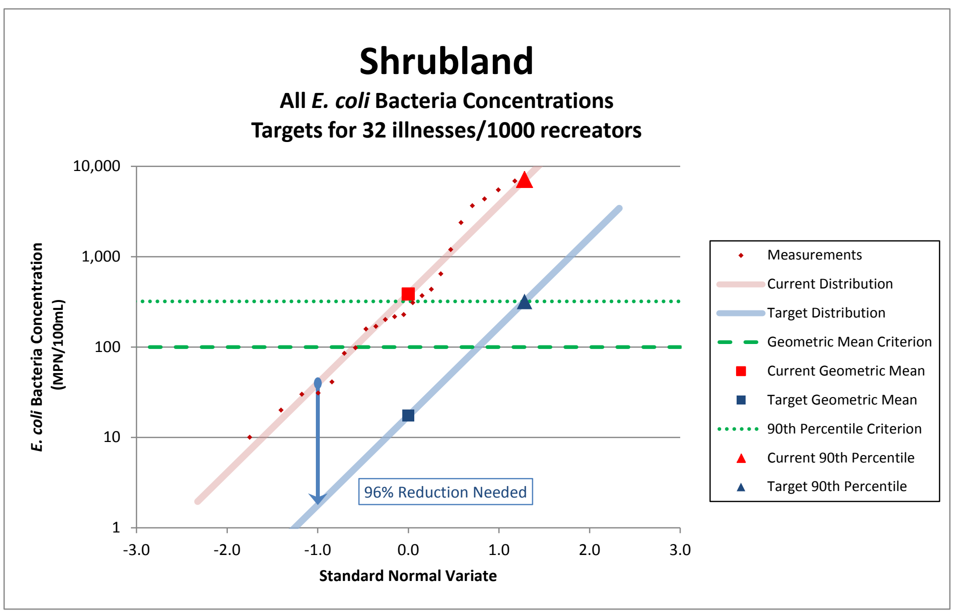

Figure 25. Comparison of all *E. coli* bacteria concentration measurements collected from shrubland areas in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

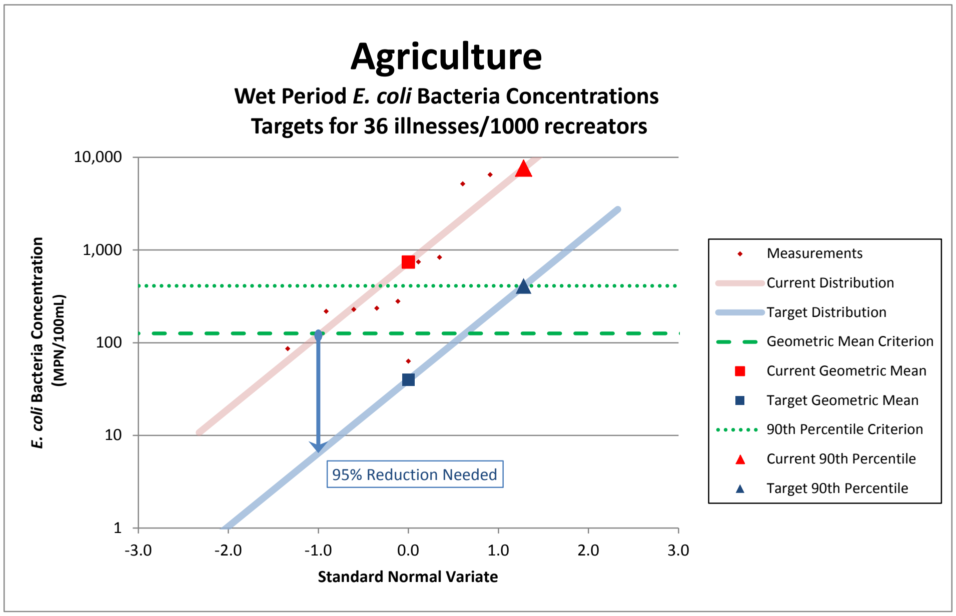

Figure 26. Comparison of E. coli bacteria concentration measurements collected from agricultural areas during wet periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

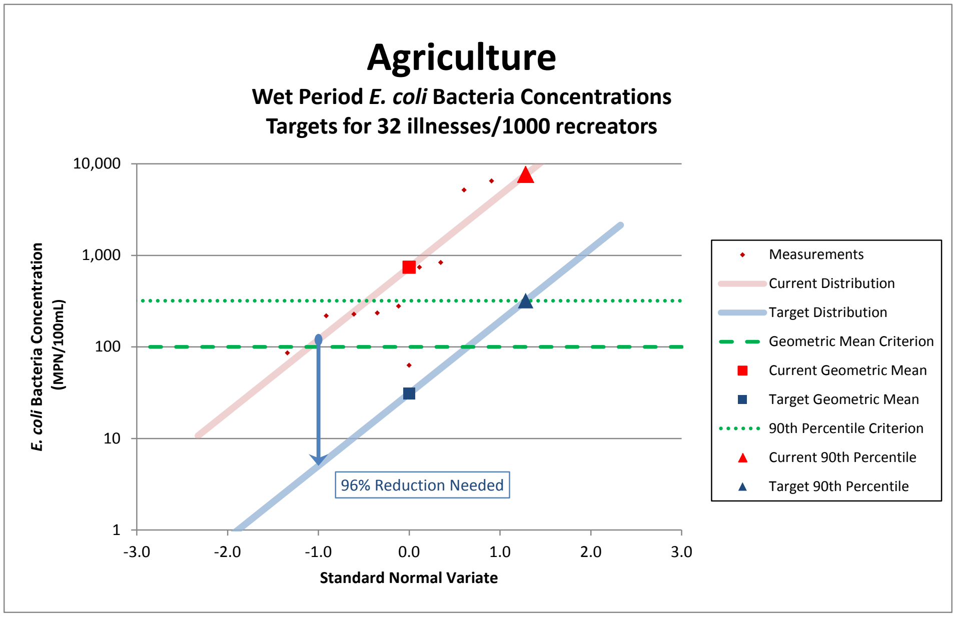

Figure 27. Comparison of *E. coli* bacteria concentration measurements collected from agricultural areas during wet periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

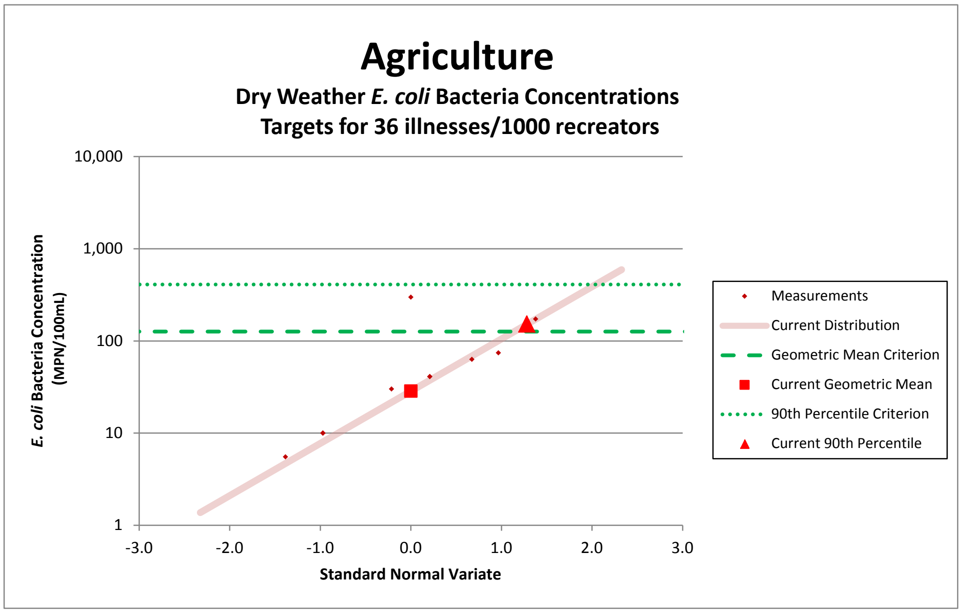

Figure 28. Comparison of *E. coli* bacteria concentration measurements collected from agricultural areas during dry periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

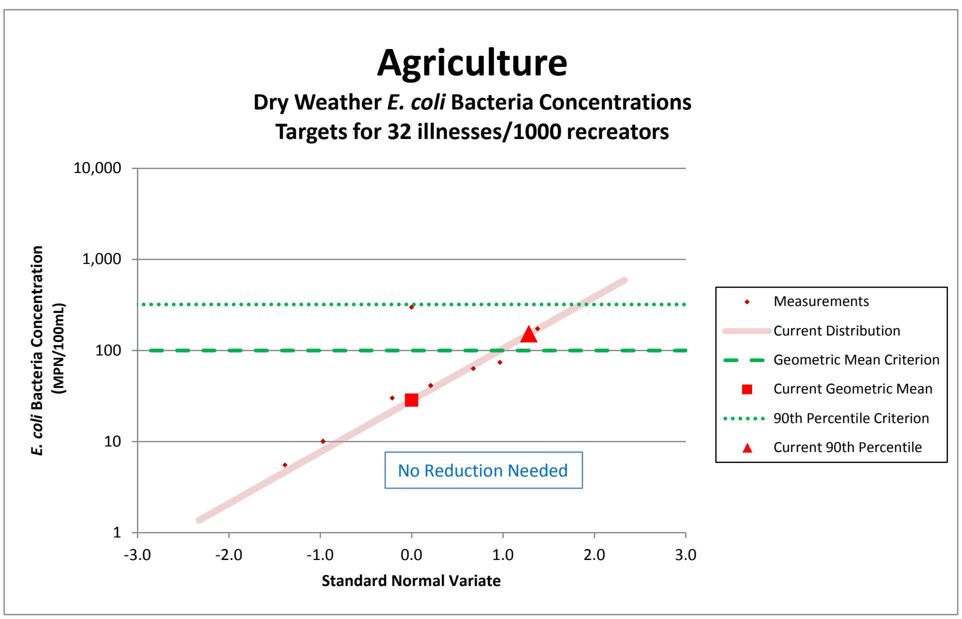

Figure 29. Comparison of *E. coli* bacteria concentration measurements collected from agricultural areas during dry periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

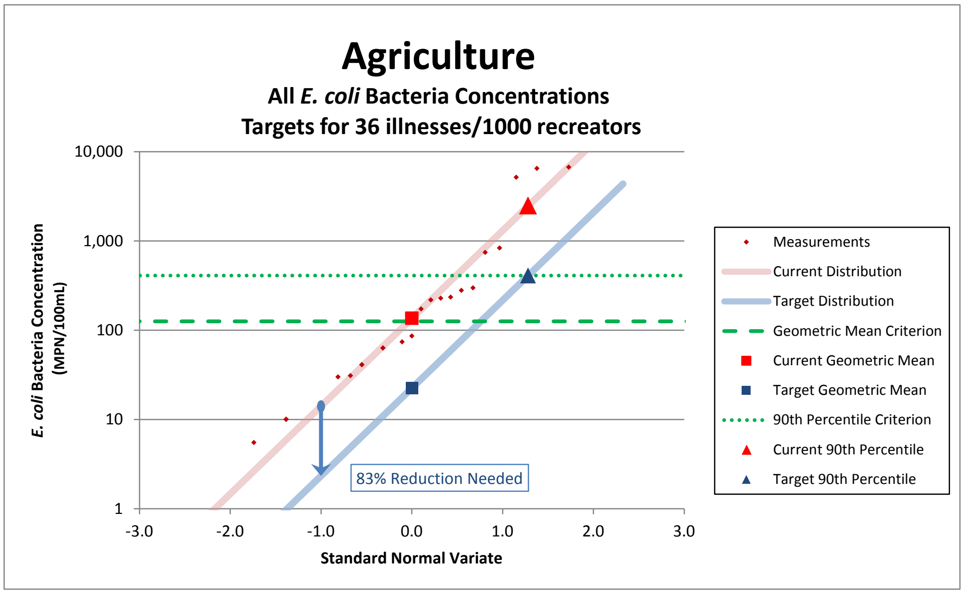

Figure 30. Comparison of all *E. coli* bacteria concentration measurements collected from agricultural areas in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

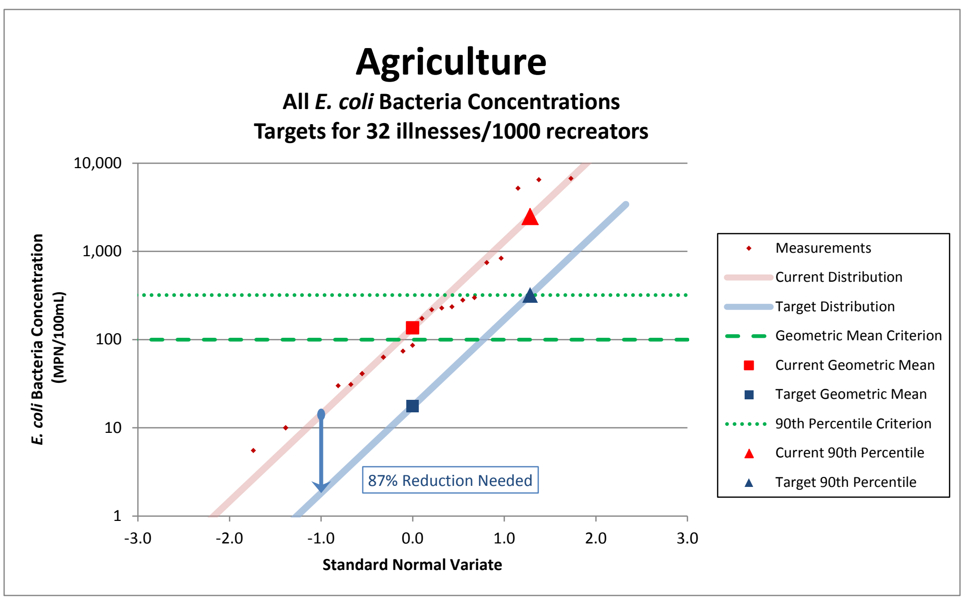

Figure 31. Comparison of all *E. coli* bacteria concentration measurements collected from agricultural areas in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

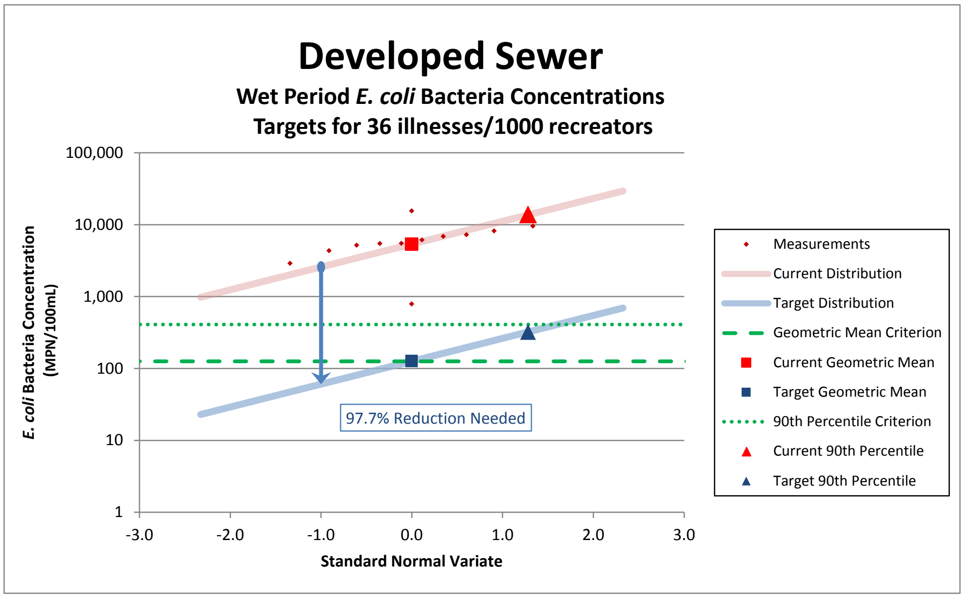

Figure 32. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with sewer connections during wet periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

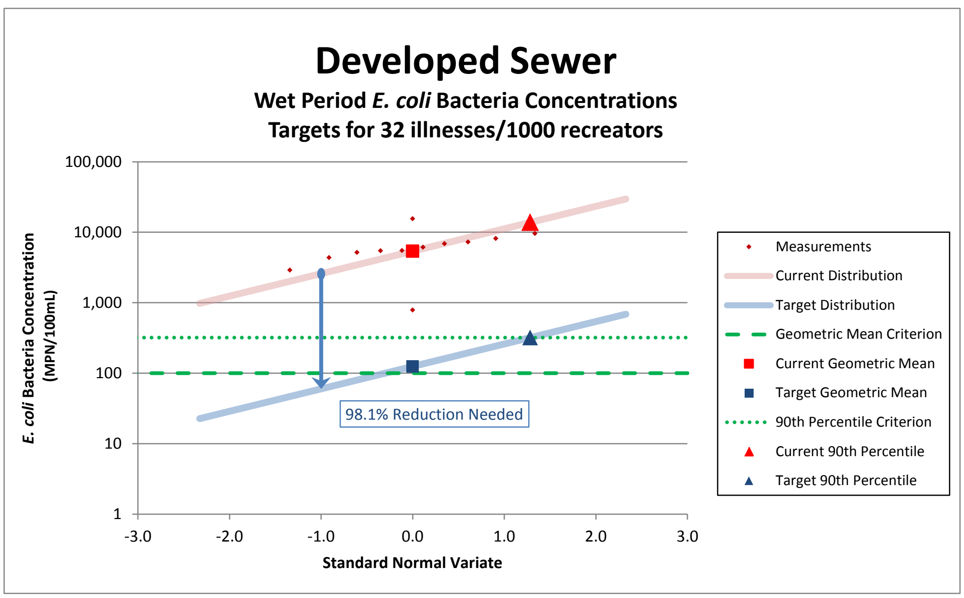

Figure 33. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with sewer connections during wet periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

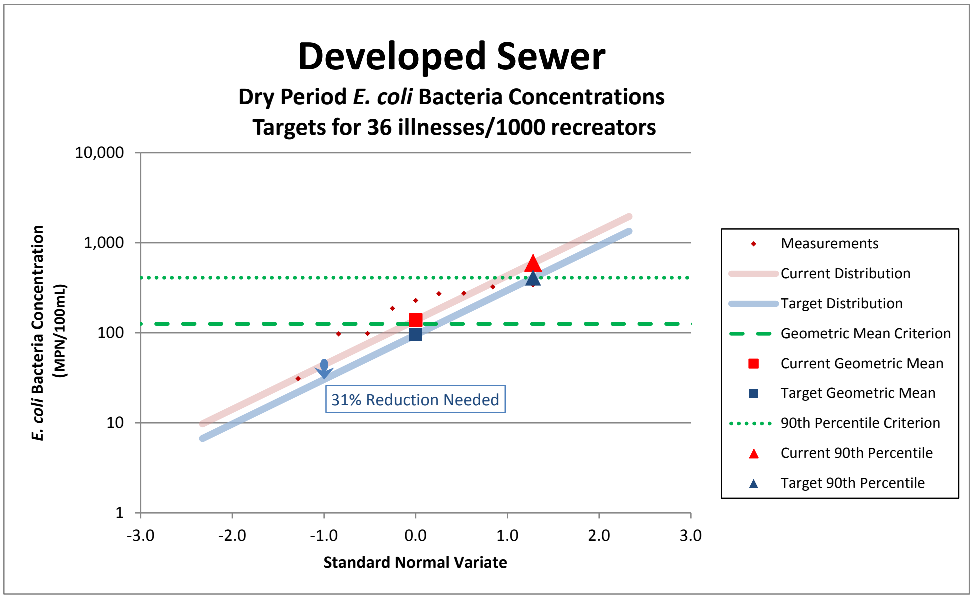

Figure 34. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with sewer connections during dry periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

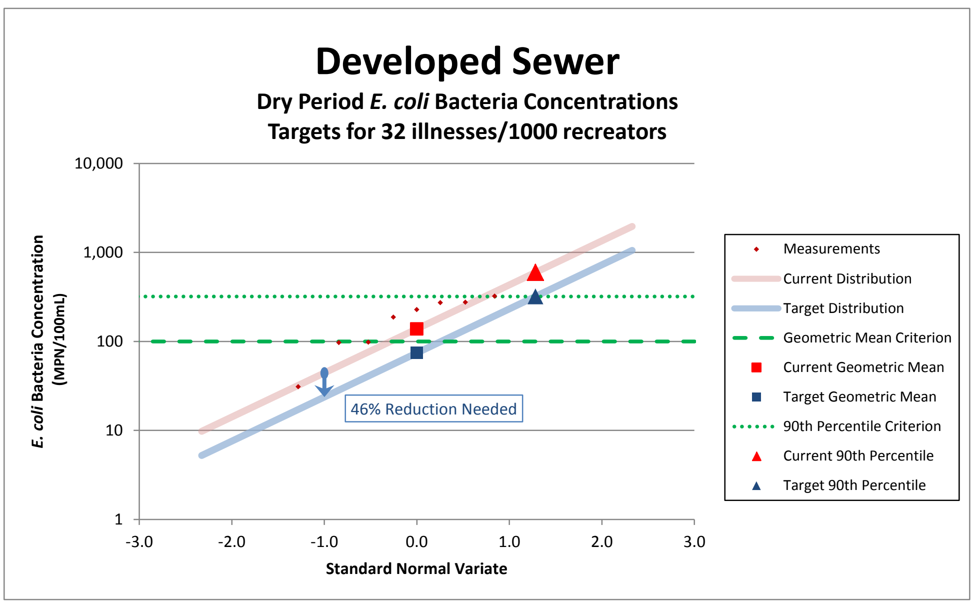

Figure 35. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with sewer connections during dry periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

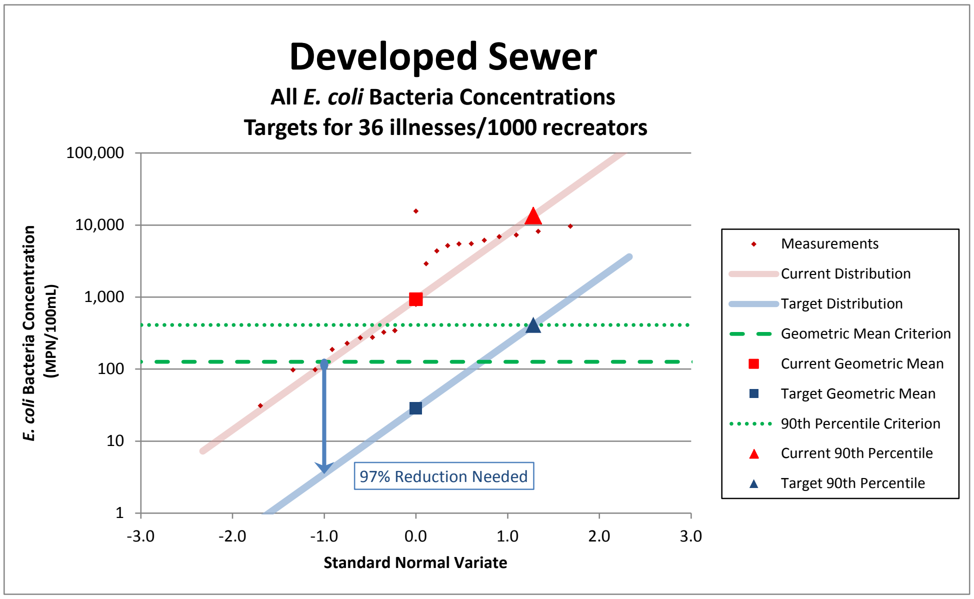

Figure 36. Comparison of all *E. coli* bacteria concentration measurements collected from developed areas with sewer connections in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

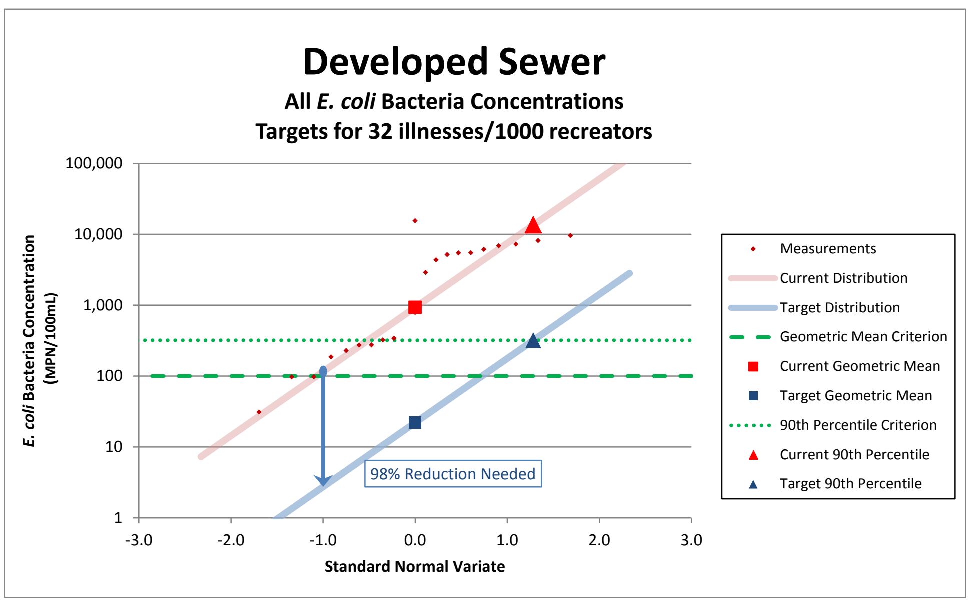

Figure 37. Comparison of all *E. coli* bacteria concentration measurements collected from developed areas with sewer connections in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

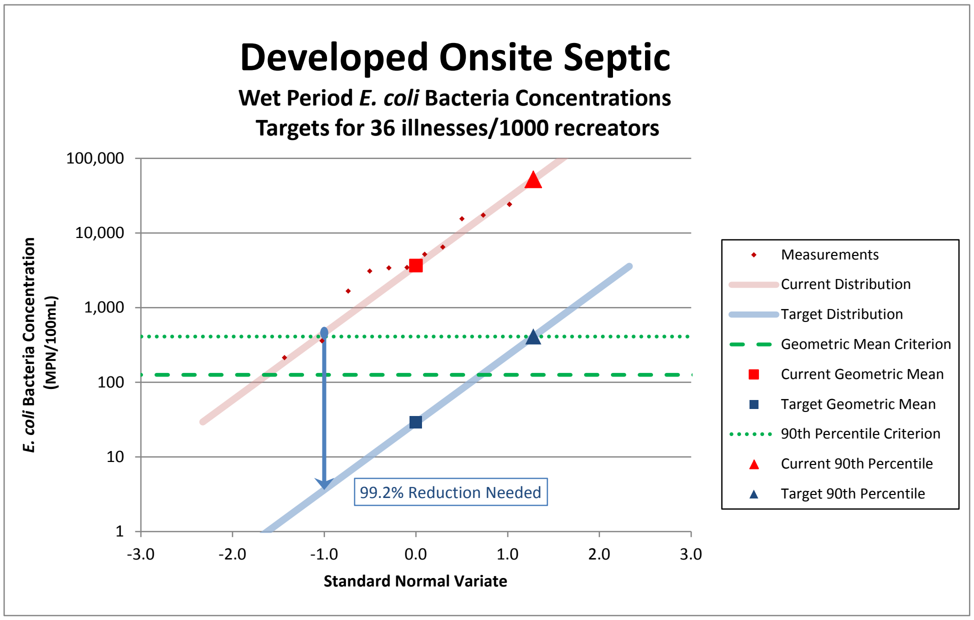

Figure 38. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems during wet periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

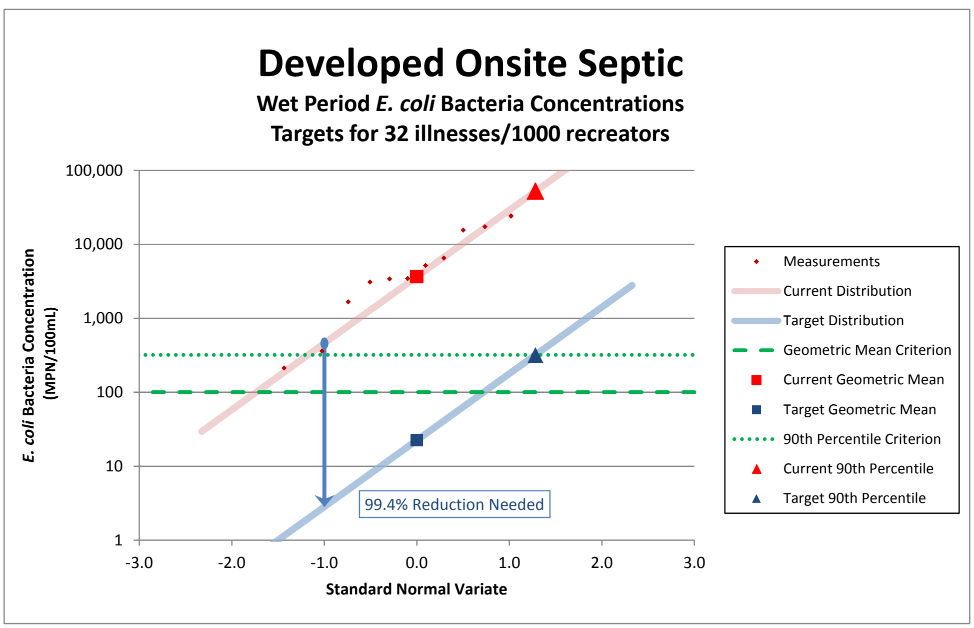

Figure 39. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems during wet periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

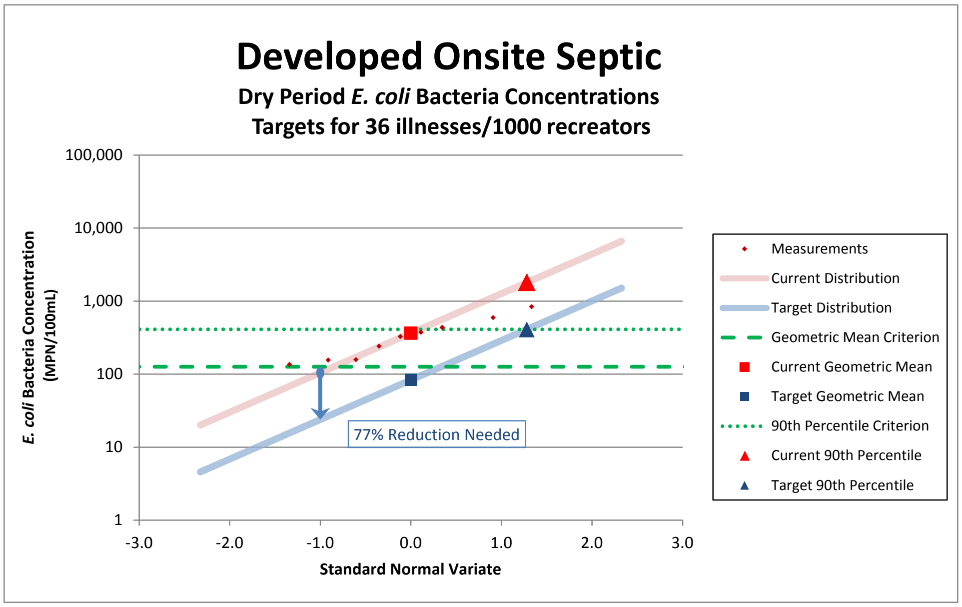

Figure 40. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems during dry periods in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

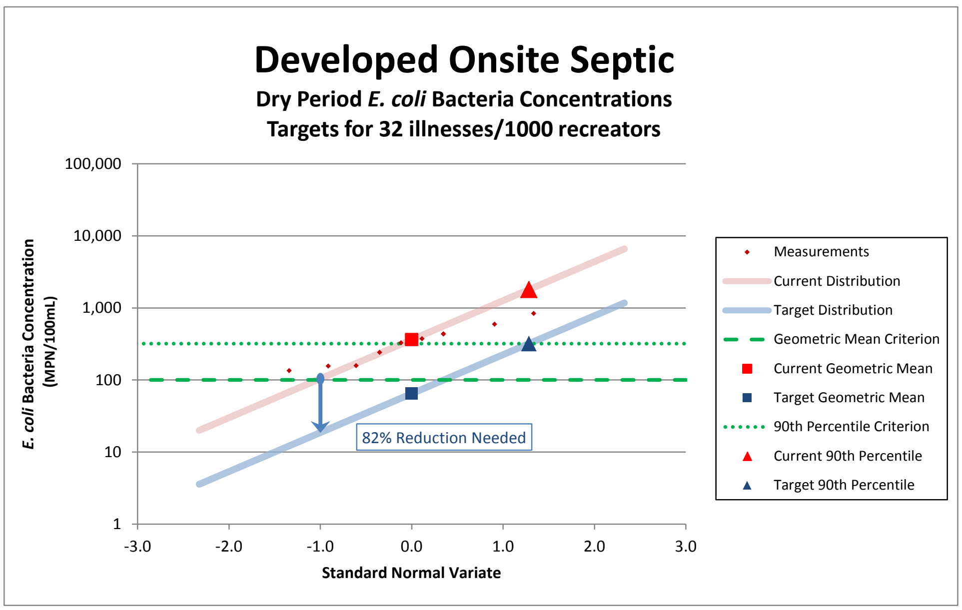

Figure 41. Comparison of *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems during dry periods in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators

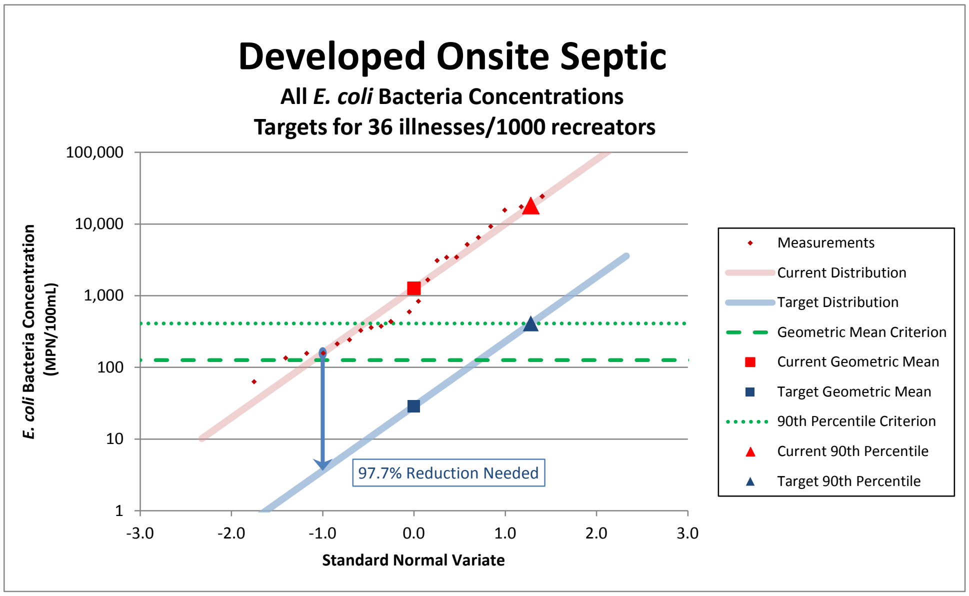

Figure 42. Comparison of all *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems in the Russian River to concentration targets for estimated 36 illnesses per 1,000 recreators

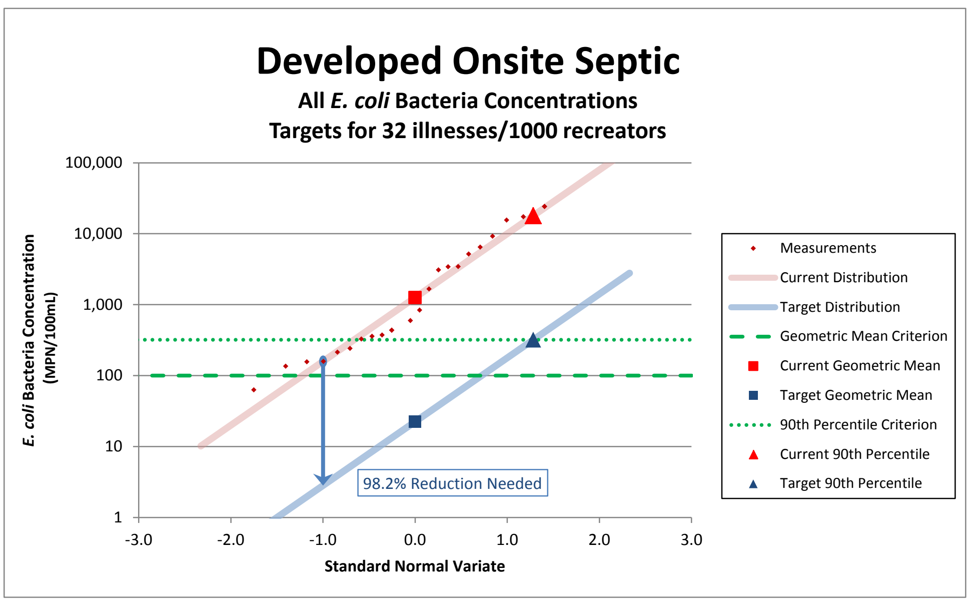

Figure 43. Comparison of all *E. coli* bacteria concentration measurements collected from developed areas with onsite septic systems in the Russian River to concentration targets for estimated 32 illnesses per 1,000 recreators