Memorandum

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Date: *April 15, 2015*

Subject: *Residential Property Scale Bacteria Water Quality Study – Interim Data Analysis*

Background

Since adoption in 2012, the Permittee MS4 programs have been actively implementing the Comprehensive Bacteria Reduction Plan (CBRP). The CBRP is a long term plan designed to achieve compliance with dry weather flow (DWF) wasteload allocations for bacterial indicators established by the Middle Santa Ana River (MSAR) bacterial indicator TMDL. The CBRP includes a schedule of activities, which in the 2012-2014 dry seasons required implementation of Tier 1 and Tier 2 bacteria source evaluation activities. To date, Tier 1 source evaluations have been completed in 2012 as well as the two years of Tier 2 source evaluations (2013 and 2014). Tier 2 source evaluations in 2013 and 2014 were very different and each provided key information toward demonstrating compliance with the TMDL.

Tier 1 source evaluations conducted in 2012 focused monitoring on all major MS4 outfalls to TMDL waters (n = 34) for purposes of prioritization of upstream Tier 2 source evaluation and mitigation, where possible, in the 2013 and 2104 dry seasons. The goal of Tier 2 source evaluations is to identify specific controllable urban sources of fecal bacteria within MS4 drainage areas and to take action wherever possible to eliminate these sources. In 2013, Tier 2 source evaluations involved rigorous monitoring activities to track down specific sources of bacteria within prioritized MS4 networks, employing similar methods to the Center for Watershed Protection Illicit Discharge Detection and Elimination (IDDE) guidance (Center for Watershed Protection, 2004). The 2013 Tier 2 source evaluations efforts were effective in tracking down a few specific sources of bacteria for mitigation action; however it was the opinion of the TMDL Task Force that extrapolation of this technique over much larger tributary areas would be infeasible. Given this, and limited scientific understanding of specific sources of fecal indicator bacteria (FIB) in urban watersheds during dry weather, the Cities of Chino and Chino Hills developed the Residential Property Scale Bacteria Study ("Study" hereafter) to serve as the 2014 Tier 2 source evaluation. The primary objective of the Study is to characterize *E. coli* concentrations in DWF resulting from irrigation of residential properties in the Cities of Chino and Chino Hills in San Bernardino County, California.

Study Questions

One common finding of most water quality monitoring programs investigating FIB in urbanized watersheds is that results show extreme variation with samples ranging from non-detect to exceeding the range of measurement even after multiple dilutions, typically >24,000 mpn/100 mL (Urban Water Resources Research Council, 2014). This was also a general finding throughout the MSAR watershed for samples collected from MS4 outfalls and within networks in the 2012 and 2013 dry seasons (SAWPA, 2013). In fact, it was noted that such variability was discovered even when evaluating weekly samples collected during dry weather conditions from the same site and at similar times of day. Such results have led many scientists to broadly characterize FIB in urban watersheds as 'ubiquitous' (UWRRC, 2014; Noble et al., 2006; CWP, 2000), because high counts seem to be widespread spatially and temporally. This Study investigates the corollary condition, whereby FIB sources come from drainage areas that are identifiable and distinct from uncontaminated areas.

One hypothesis that may explain the apparent extreme variability in results is that bacteria washoff is linked to the quantity and quality of irrigation excess runoff from individual properties. Unlike rainfall driven runoff, where rain is spread across the entire watershed, the primary source of DWF in an urban catchment at any given point in time is outdoor water use by a single or small group of properties. This hypothesis led the Cities of Chino and Chino Hills to identify two key scientific questions, which if better understood after investigation, could influence regional bacteria source management approaches, as follows:

- What is the proportion of properties with elevated DWF and/or FIB concentrations that may be contributing to downstream impairments? This question was effectively addressed through the implementation of the Study as will be presented in this technical memorandum.
- Are there any unique characteristics of properties with elevated concentrations of FIB (focus group), including but not limited to the specific sources of fecal bacteria and reasons for excess water waste? The Study results did not discern any significant explanatory variables for properties with high FIB and the investigators believe this should be a focus for any future source evaluation activities

Data from the Residential Runoff Reduction (R3) Study by Irvine Ranch Water District (IRWD) and Metropolitan Water District of Orange County (MWDOC) validate this hypothesis (A & N Technical Services, 2006). The R3 study involved installation of flow gauges downstream of several residential neighborhoods in Orange County. These gauges measured DWF that extended throughout most of the day indicating that not all properties generate irrigation excess runoff at the exact same time of day. The typical duration of an irrigation station is less than 15 minutes, thus FIB from a given property can only generate irrigation excess during a brief period of a day, excepting any substantial malfunction or misuse. Accordingly, a sample taken at any given time downstream of a residential neighborhood is likely only representative of the properties that were actively generating irrigation excess runoff immediately prior to the sample collection. In other words, consecutive (with more than 15 minute separation) samples within MS4s or at outfalls taken from the same site may be representative of completely different contributing subareas.

Through Tier 2 field reconnaissance, it has been observed that the predominant source of DWF at MS4 outfalls throughout the MSAR watershed is irrigation excess runoff from residential properties (personal communication with Ruben Valdez and Robert Vasquez, March 18, 2015). A study of dry weather bacterial water quality in San Diego determined that 80 percent of DWF from residential MS4 outfalls is from irrigation excess runoff (Weston, 2009). Numerous factors impact which property(ies) would be creating irrigation excess runoff at the time a downstream sample is collected, including irrigation schedules, irrigation system efficiency, and timing of other outdoor water uses, which are a function of the day to day routine of each resident at each property. Figure 1 shows an example of a field visit in the City of Chino where DWF inputs to the MS4 at the time of the photograph are clearly generated from irrigation excess from a single property of a street block. Most residential irrigation excess DWF is conveyed from an individual landscaped zone to the street gutter in one of two ways; either as sheet flow across the sidewalk and/or driveway (Figure 1a) or via a small underdrain that has an outfall in the curb and is typically used to collect excess runoff from a backyard (Figure 1b).

Figure 1
Typical irrigation excess runoff from front yards (a) and back yards via an underdrain (b)
Photo credit: Ruben Valdez

Methods

Together the Cities of Chino and Chino Hills visited over 300 randomly selected residential properties in the Cypress Chanel (CYP) and Boys Republic South Channel (BRSC) drainage areas to observe DWF conditions and where possible, collect water quality samples for bacteriological analysis. Table 1 provides an inventory of field visits and water quality sample collection over the course of the Study within the investigated MS4 drainage areas. The field crews targeted early morning hours (between 4:00am and 8:00am) to perform site visits in order to increase the likelihood of encountering DWF when residents are more likely to have scheduled irrigation timers per landscaping recommendations. The early morning sampling was also appropriate because travel times from an individual property to TMDL waterbody segment would lag the delivery of irrigation excess to receiving waters until mid-day when there is the greatest exposure potential from water contact recreational use.

Table 1. Dates and number of site visits and samples collected from each subwatershed during the Study

Sampled Week	BRSC		CYP		Total Sum of Visits	Total Sum of Samples
	Visits	Samples	Visits	Samples		
8/21/2014	21	8	10	0	31	8
8/28/2014	32	11	11	0	43	11
9/3/2014	47	9	12	3	59	12
9/11/2014	30	8	9	2	39	10
9/18/2014	20	8	10	4	30	12
9/25/2014	33	11	11	3	44	14
10/2/2014	12	3	12	4	24	7
10/9/2014			12	2	12	2
10/17/2014			9	4	9	4
Total (2014)	195	58	106	22	301	80

The Study design recognized the challenge of collecting water samples from a randomly selected address, given the expected short duration of irrigation excess runoff from a randomly selected property (<30 minutes), and therefore involved an unbiased protocol to locate nearby DWF for collection of field observations and water samples (Figure 2). The protocol involved tracking any DWF in the street gutter adjacent to the randomly selected address to its most upstream source. Field observation and water samples are then collected at the address of the residential property that is the most upstream source of DWF.

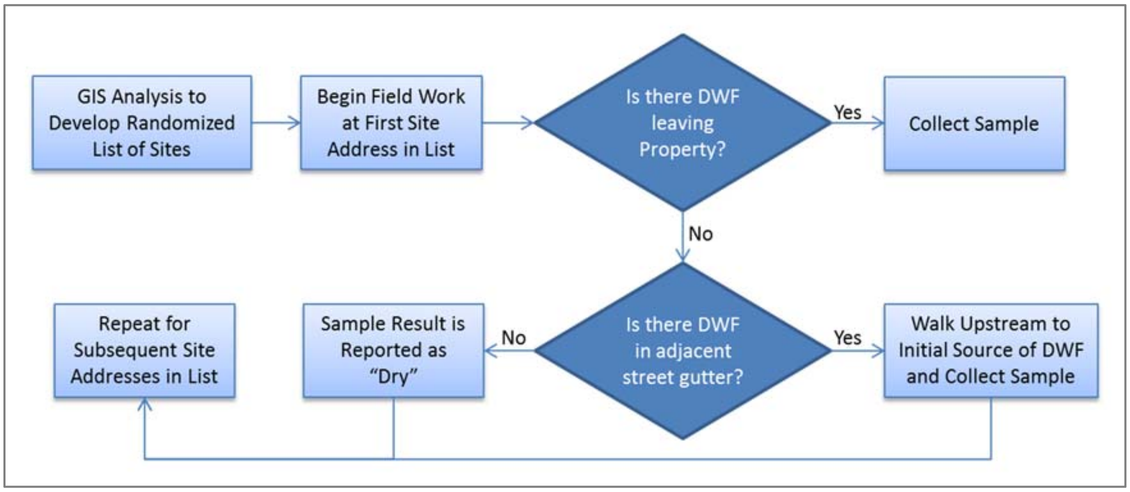

Figure 2
Flowchart showing the method used to locate a moniotring site from a randomized property address for field observation and water sample collection

Care was taken to follow field sampling protocols detailed in a Regional Board approved QAPP for sample collection to avoid contamination by the sampler (http://www.sawpa.org/wp-content/uploads/2013/01/MSAR-QAPP-July-2013.pdf). Samples of DWF stored in iced coolers and chains of custody were delivered to Weck Labs in Industry, CA (weeks 1-3) and Clinical Labs in San Bernardino, CA (weeks 4-9) for analysis of *E. coli* concentration using the IDEXX Colilert method (SM 9223B). One QA/QC sample was collected at each field campaign including a replicate and equipment blank.

Figure 3
Typical sample collection using syringe and handheld pump
Photo credit: Andy Zummo

Field observations included address of sampled property, description of the source of dry weather flow, if identifiable (e.g. front yard irrigation, backyard irrigation, car washing, etc.), qualitative descriptions of relevant water conditions (e.g., color, clarity, flow category, trash, odors, pets) and weather (e.g., wind, rain) at the time of sample collection.

Results

Summary statistics for each of the subwatersheds are presented in Table 2. Geometric means of *E. coli* from properties in the BRSC and CYP drainage areas were 101 and 233, respectively. When pooling the data from both drainages, the geomean of all 80 properties is 127 mpn/100mL. The data show wide variability with many samples at the limits of detection (typically 10 mpn/100mL) or upper range of countable measurement (typically 24,000 mpn/100mL). A similar range of concentration was observed in a study of irrigation excess runoff *(n=23*) in Orange County, CA coastal drainages (Rippy et. al., 2014). As shown in Figure 4, a single-component lognormal model provided the best fit to the distribution of data from the pooled data. Given the data are skewed, the arithmetic mean is much greater than the geomean or median, as shown in Table 2.

Table 2. Summary statistics for *E. coli* concentration

Statistic	*E. coli* concentration (mpn/100mL)		
	Boys Republic South Channel (n = 58)	Cypress Channel (n = 22)	Pooled Study Data (n=80)
Geomean	101	233	127
Coefficient of variation	0.56	0.34	0.50
Minimum	1	10	1
Median	84	205	119
Arithmetic Mean	1,548	1,056	1,413
Maximum	24,196	9,200	24,196

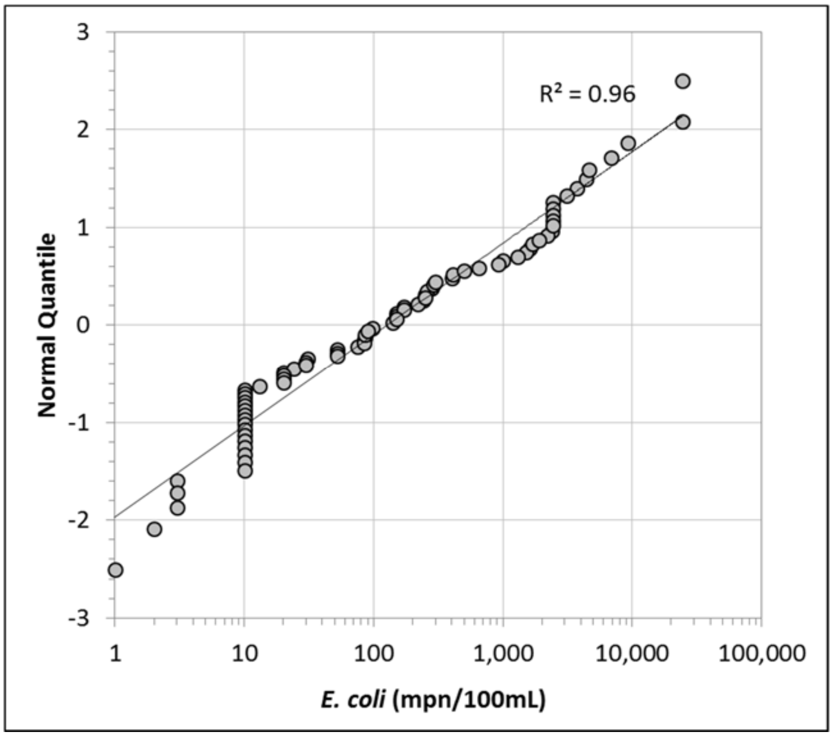

Figure 4
Probability plot showing pooled *E. coli* concentration data fitted to an exponential model

The coefficient of variation (CV; standard deviation divided by the mean) of 0.50 for the pooled data set exceeds the CV from any prior dry season monitoring within receiving waters or MS4s of the MSAR watershed, which was greatest (CV=0.33) in the 2013 dry season Tier 2 source evaluation. This is expected because DWF within MS4s is a mixture or blend of the highly variable residential concentrations, and thus as a mixture would naturally be expected to exhibit lower variability than the contributors. The Study data provides a more spatial discretized dataset and therefore a higher CV is expected.

For the 2014 Study data, a workbook application was developed that uses bootstrapping to estimate a population parameter representing the fraction (percentage) of the population above a certain *E. coli* concentration threshold, along with the margin of error (or confidence interval) for the estimated parameter. Bootstrapping is resampling of the dataset with replacement, a nonparametric method of estimating a population parameter from a random sample. The workbook application generates bootstrap statistics for a selected threshold. The statistics shown in Table 3 are described below:

- Sample Size – Sample size for the calculation, either the actual sample size (*n* = 81 for the Phase II dataset) or a different sample size for purposes of sample power analysis.
- Population Value – Population threshold (e.g., proportion above 235 MPN/100mL).
- Confidence Level – Desired confidence level for the calculation (e.g., 95%).
- Number of Resamples – Number of bootstrap iterations, i.e., number of times the sample is resampled (e.g., 10,000).
- Mean Fraction – Average fraction (%) of the resamples that are above (greater than) the population value of concern or threshold (e.g., 39.5%).
- Lower Confidence Limit – Estimated lower limit of the mean fraction at the desired confidence level (e.g., 28.4%).
- Upper Confidence Limit – Estimated upper limit of the mean fraction at the desired confidence level (e.g., 50.6%).
- Margin of Error – Estimated error (+/-) for the mean fraction, i.e., one-half of the upper confidence limit minus the lower confidence limit (e.g., 11.1%).

The output of the bootstrapping is reported in Table 3 for the average percentage of the population above an *E. coli* value of 235 mpn/100 mL, the current single sample maximum (SSM) water quality objective, and 410 mpn/100mL, a recently published statistical threshold value (STV) for freshwaters (EPA, 2012). Results indicate that at the 95 percent confidence level, 41.2% ± 11.3% of the population of properties in the two drainages would be expected to exceed the SSM, and that 29.9% ± 10.0% would be expected to exceed the STV. The same bootstrapping method was applied to determine the uncertainties in the arithmetic and geometric mean *E. coli* concentrations, resulting in an estimated 95 percent confidence interval of 674 to 2384 mpn/100mL for the arithmetic mean and 68 to 200 mpn/100mL for the geometric mean (Table 4).

Table 3. Results of the Bootstrapping Analysis for Percent Exceedence Analysis

Sample Size	80	80
Population Value	235	410 [1]
Confidence Level	95	95
Number of Resamples	10,000	10,000
Mean Fraction of Exceedences	41.2	29.9
Lower Confidence Limit	30.0	20.0
Upper Confidence Limit	52.5	40.0
Margin of Error	±11.3	±10.0

1) STV recommended in Recreation Water Quality Criteria (EPA, 2012). This STV is based on use of a different analytical method (EPA 1603) than was employed in this study; however, results have been shown to be comparable within +/- 15 percent (Buckalew et al., 2006)

Table 4. Results of the Bootstrapping Analysis for Estimation of Population Central Tendency

	Mean	Geomean
Sample Size	80	80
Confidence Level	95	95
Number of Resamples	10,000	10,000
Confidence Level	95	95
Lower Confidence Limit	674	68
Upper Confidence Limit	2384	200
Margin of Error	-741 to +969	-53 to +80

Power analyses were also conducted to assess the dataset sizes needed to reduce the margin of errors or confidence intervals for planning of supplemental source evaluation studies. For the percent exceeding determination (Figure 5), results indicate that reducing the margin of error from about ±10 percent with the current data set of n=80 to about ±5% would require a sample size of over 300 samples, or an additional 220 samples. Correspondingly, such a sample size increase would decrease the 95% confidence interval around the mean from 674 - 2384 MPN/100mL (n=80) to 998 -1892 MPN/100mL (n=300), and would decrease the 95% confidence interval around the geomean from 68 – 200 MPN/100mL (n=80) to 87 – 153 MPN/100mL (n=300)

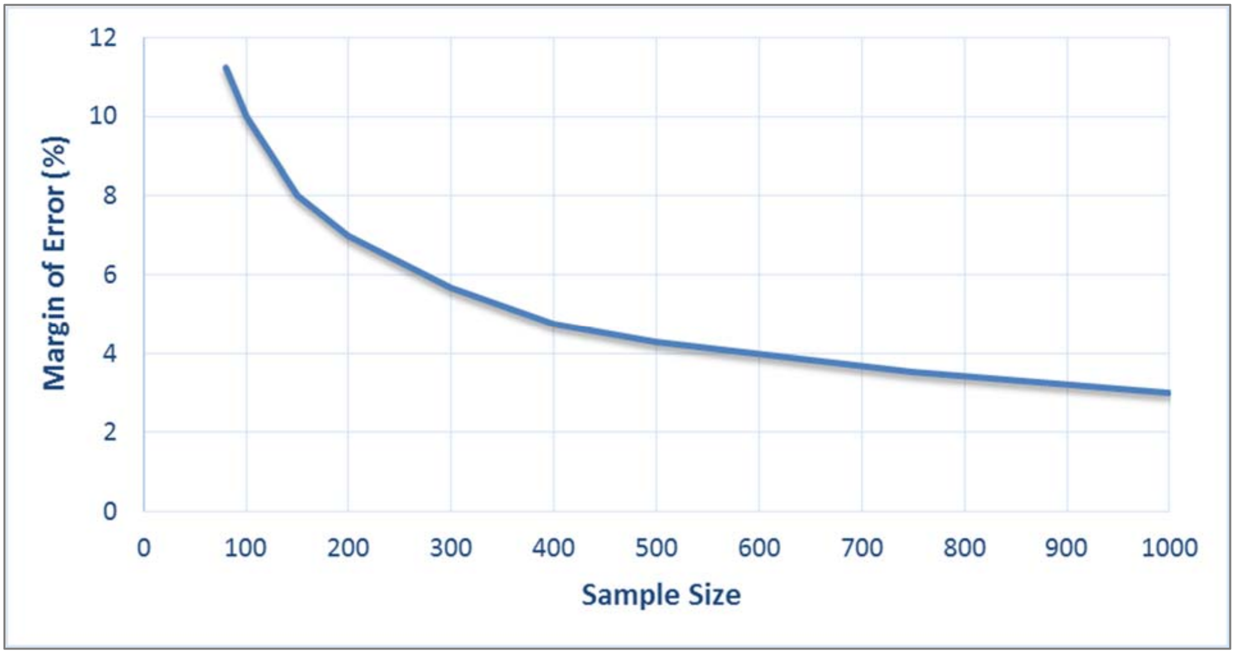

Figure 5
Power analysis for E. coli > 235 MPN/100mL for Margin of Error as a function of sample size

Potential Explanatory Variables

The dataset also included field observations, which were used to separate *E. coli* data into different groups that could be compared to determine whether differences between the groups are statistically significant. Field observations and desktop analysis of aerial imagery did not reveal any characteristics of residential properties to differentiate sampled properties. Attachment A contains field observations and photographs recorded by staff from the Cities of Chino and Chino Hills. None of the sampled properties appeared to have any obvious sources of fecal, except for a few where dogs were noted in the backyard.

One significant explanatory variable identified in the Study was the flowpath where samples were collected between the irrigation sprayhead and MS4. Three distinct types of flowpaths for irrigation excess runoff sampled during the Study were identified:

- Many properties are developed with small diameter (<4") perforated backyard drains designed to convey water from oversaturated soil to the MS4. Typically, such drains are within 1 foot of the ground and outflow to the street gutter through an opening in the curb (see Figure 1b above);
- The soils underlying typical front yards are highly compacted and often cannot percolate irrigation water at the rate it is applied. Consequently, a portion of the irrigation water moves laterally downgradient through the thatch and ultimately exits the lawn and becomes sheet flow over sidewalks and driveways, and
- Some samples were collected directly from street gutters immediately downstream of the randomly selected address and may include a blend of DWF from upstream properties.

E.coli concentrations from the three flowpath groups are shown as box-whisker plots in Figure 6. Possible significant differences between the three sampled flowpaths were tested using the computer program ProUCL (USEPA, 2013). Both parametric on the log-transformed data and nonparametric tests on the ranked data were conducted. First, an analysis of variance (ANOVA) was conducted to determine whether there was a statistical difference among the three groups. The respective p-values were 0.0144 (parametric ANOVA) and 0.0125 (nonparametric ANOVA) which, since both p-values are below the critical alpha level of 0.05, indicate that indeed there is a statistically significant difference among the three groups. Next, multiple comparison tests were conducted to identify which of the individual groups are statistically different. The multiple comparison tests were parametric t-tests and nonparametric Wilcoxon-Mann-Whitney (WMW) tests. However, since the multiple comparisons involved multiple applications of the two tests, the critical alpha level was adjusted via the Bonferroni method by dividing the overall alpha by the number of groups (i.e., 0.05/3 = 0.017) to guard against inflation of the false positive error rate. The multiple comparison tests indicated that only front yard versus gutter is statistically different (p-value = 0.005 for both the parametric t-test and nonparametric WMW test); front yard versus back yard, and back yard versus gutter were not statistically different (p-value > 0.017).

Discussion

Irrigation water is potable when it is emitted from spray heads and has the potential to washoff FIB as it travels through lawns and other landscape areas to street gutters into MS4s and then to receiving waters. The Study collected samples from very small drainage areas, sometimes as small as the active irrigation zone at the time of sampling (~500 ft^2). A key question is whether such a small drainage area can significantly influence downstream water quality. In addressing questions related to water quality, it is first and foremost necessary to understand the hydrologic processes associated with downstream flow, in this case during the dry season. Data collected from MS4 outfalls to receiving waters in the Santa Ana River watershed conducted in 2011-2014 identified a persistent and not negligible rate of dry weather flow from urban drainage areas to tertiary treated effluent dominated receiving waters (SAWPA, 2013). Thus, bacteria contribution in irrigation excess runoff from residential properties, taken as a whole, are a key factor to complying with the TMDL requirements.

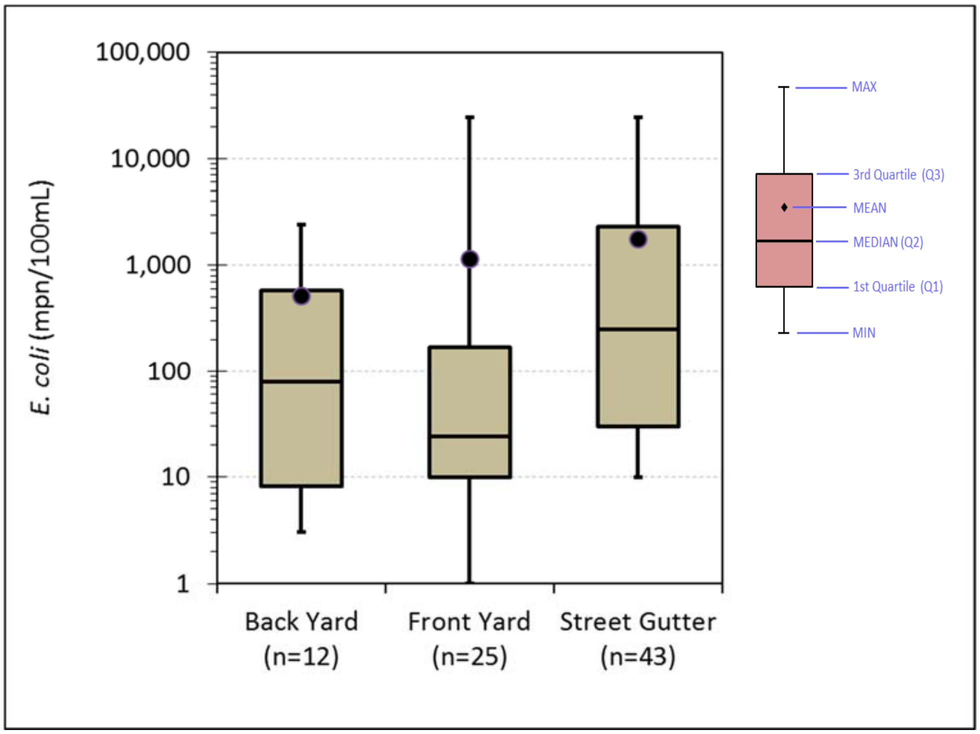

Figure 6
Box-Whisker Plots for *E. coli* Concentration for Samples from Front Yard, Back Yard, and Street Gutter Flowpaths

The lognormal distribution of *E.coli* concentration indicates that variability is related to differences in sources areas at the property scale, and that it is likely that elevated bacteria levels measured at MS4 outfalls may be caused by a minority of proprieties that contain a source of FIB. The concentration of E. coli at an MS4 outfall would be approximated by computing a flow-weighted average of irrigation excess from all properties contributing DWF at the point of sampling. Assuming, the rate of irrigation excess DWF is similar for many properties, then the *E. coli* concentration of inputs to the MS4 would be equal to the arithmetic mean shown in Table 2. Thus, a small fraction of properties may cause very high *E. coli* concentrations in DWFs to the MS4 compared with a typical (50th percentile) property. In other words, a majority of properties may not cause or contribute to impairments of recreational use in downstream receiving waters. This finding serves to further reduce the area of concern for watershed managers within prioritized subwatersheds. Moreover, prioritization of watershed management actions at the subwatershed scale, as it commonly employed, may overallocate resources in some areas while neglecting to address sources in others. Given this conclusion, several scenarios should be considered by watershed managers charged with meeting WLAs in the MSAR bacteria TMDL, as follows:

- If the source of FIB is identifiable and determined to be controllable, then watershed managers will have the ability to conduct enhanced source control throughout their MS4 drainage areas, such as with a combination of targeted education and outreach and code enforcement. Effective control of select properties may be achieved by reducing irrigation excess runoff, as opposed to imposing restrictions involving other behaviors.
- If the source of FIB is identifiable and determined to be uncontrollable, watershed managers may demonstrate that human activities associated with the urban environment are not directly causing or contributing to downstream impairments of recreational use. Uncontrollable sources of bacteria in this watershed area have been defined in a recent Basin Plan Amendment (CITE) and include several that may exist within residential neighborhoods; wildlife activity and waste, bacterial regrowth within sediment or biofilm, and resuspension from disturbed sediments.
- Lastly, if the source of FIB is not identifiable, then it may be the case that enhanced source control could be ineffective by not focusing on the key source, and instead watershed managers would be best served through further study (such as is proposed below) or implementation of downstream controls.

One significant explanatory variable was identified suggesting significantly higher *E. coli* concentrations in samples collected from street gutters, as opposed to from backyard drains or sheet flow from front yards. This finding suggests that the most important source of FIB from residential neighborhoods may be from street gutters and not residential lawns. A similar conclusion was drawn from a special study conducted by the City of Newport Beach. Potable hose water was discharged to four residential street gutters and samples collected from the same street gutter at a downstream site were found have been enriched with FIB to levels well above recreational use standards, ranging from 230-14,000 cfu/100mL (Skinner et al., 2009).

The presence of indicator bacteria in biofilms has been hypothesized to be the reason for their extended survival in sediments and their ability to act as a loading source to the overlying water (Ferguson, 2006; Sanders et al., 2005). Additionally, the presence of biofilm is believed to explain fecal indicator bacteria regrowth in storm drains; in one study, concentrations increased three to four order of magnitude over 48 hours (Martin and Gruber, 2005). Surbeck et. al. (2010) studied FIB survival and growth in Cucamonga Creek, a large open flood control channel, and concluded that FIB are not “static pollutants with land used based characteristics, but rather an ecological phenomenon, in which a dynamic balance between sources, nutrient availability, competition with other heterotrophic bacteria, and predator prevalence determines the magnitude and extent of FIB pollution and its human health implications”. Although not well studied to date, biofilms may also exists within segments of typical residential street gutters with favorable conditions. If so, it may be possible that irrigation excess runoff acts as an indirect source of FIB to street gutters, where survival and exponential growth is supported by a wetted habitat, prior to resuspension and transport to the MS4 network. Conversely, others have found that direct inputs of FIB to MS4s, are a more important source than growth and resuspension from biofilms in urban subwatersheds, especially when human sewage sources are discovered (Ekklesia et. al., 2014; Sercu et al., 2009).

At this point in time, an obvious source of FIB was not determined from field observations and *E. coli* concentrations alone, although the importance of sediment and biofilm in street gutters as potential habitat provides a useful clue for developing supplemental monitoring and for focusing watershed management actions. There are many possible sources of FIB to street gutters and ultimately to MS4s and receiving waters during dry weather. This Study showed that one possible source could be associated with material mobilized from residential lawns with irrigation excess runoff. But what is the source of such material? Jiang et al (2007) identified a prevalence of *E. coli* markers specific to bovine sources in samples from an urban subwatershed in Orange County, CA that was attributed to the use of cow manure that is not completely inactivated in amended mulch. Many studies of FIB in urban DWF in southern California have identified wildlife as important source (Mau and Stoeckel, 2012; Jiang et. al., 2007; Shergill and Pitt, 2004). Wildlife may be more attracted to street gutters than lawns because of the more persistent source of water for drinking or bathing. Another potential source of FIB to street gutter sediments is from vehicles tires that had traveled to an area of greater potential bacteria contamination, such as a trash facility (Chambers et al., 2009).

A subset of samples collected in this Study have been preserved for future microbial source tracking (MST) analysis. Supplemental monitoring will involve testing of these samples as well as collection of additional samples for MST analysis. If the true source (i.e. host organism from where FIB originated) can be identified, it may provide the final clue needed to determine if a predominant source and pathway for FIB exits in the residential drainage areas within the Cities of Chino and Chino Hills as well as other suburban watersheds.

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