

A Case Study of Bacterial Indicators in the Sierra Nevada and Implications for Recreational Stream Use

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ABSTRACT

The Sierra Nevada forest is a multiple-use landscape, and clean surface water in this forest is necessary to maintain the freshwater resource for humans and animals, both in the forest and downstream. Nutrient and microbial pollution from diffuse, non-point sources are a concern for stream health. Microbial pathogens can lead to gastrointestinal diseases in humans and may flow from small streams into the downstream watershed. For this reason, regular public monitoring of stream health and policy to keep surface water at safe levels are important. This study sought to quantify the amount of fecal indicator bacteria (*E. coli*) in the Willow Creek Watershed, south of Yosemite National Park. Of the samples taken, 95% were below California EPA criteria values for concern, indicating that land use in this watershed is compatible with surface water health. Furthermore, water quality at a sample sites corresponded to visual signs of ecosystem health in the area around the site, indicating that water quality of streams in mountainous areas may be estimated accurately from observing signs of stream disturbance. In relation to monitoring water quality in high elevation watersheds, government strategies for regular sampling and response to microbial indicator exceedances have procedural gaps. County governments rarely test for water quality or respond to microbial health risks, instead deferring to state policy. The California State Water Board engages in regular testing and follow-ups for water quality exceedances, but focuses attention mostly on big rivers recreation sites downstream of high elevation watersheds. My results suggest that the Willow Creek watershed has healthy water quality, but procedures for monitoring high elevation watersheds could be improved in the future.

KEYWORDS

California, *Escherichia coli* (*E. coli*), policy, Willow Creek, forest, watershed, water quality

INTRODUCTION

Ever since the United States Forest Service was established, the government has enacted policies about maintaining public lands to maximize their value to the populace. This use is a form of development, even with the preservation of the landscape's natural beauty. For example, the US government leases approximately 270 million acres of public land out for pasturing leases each year, in the western states alone. Many of these areas are characterized by wide, low plains, but cattle grazing in high elevation forests is also common practice (Carle 2009). To allow access, public lands include campgrounds, and other recreational areas such as trails and roads. Residential areas, due to their proximity with public lands, should also be considered as an aspect of land use (Walsh 2005). Furthermore, in forested areas managers conduct maintenance such as cutting down sickly trees, reducing fire risk, and starting controlled burns to keep litter levels down (Miller 2010). These are some of the most prominent ways that public lands are managed. With seventy percent of western US public lands being leased for pasture, many believe that grazing is not compatible with ecosystem conservation (Fleishner. 1994). Similarly, there is caution for the over-use of recreation areas, where humans are responsible for causing litter and pollutants around their campsites (Sierra Streams Institute 2011). One essential factor connecting contaminated areas on public lands is water. Campsites and grazing meadows are usually near streams, and preventing water contamination is a critical issue for ecological and human health.

To ascertain the threat to water quality on public forest lands, the sources of bacterial contamination must be identified. This linking can be tricky, because so many rapidly changing factors may alter the health of a stream overnight (Partyka et al. 2017). Sierra Nevada cattle ranching is one possible cause of bacterial contamination in forest watersheds (Carle 2009). Since the early 2000s, *Escherichia coli* and coliform levels have been measured to be dangerously high during the summer months, and this indicates that water flowing downstream of known grazing sites could endanger human and animal health (Derlet 2012). *Escherichia coli* is an indicator bacteria, and most varieties of it are harmless by themselves, but because *E. coli* is present in fecal matter, high amounts of it may suggest that harmful diarrheal pathogens are present (Smith 2005). However, recent studies report that levels of bacterial contamination measured throughout large swathes of the Sierra Nevada generally fall within standard range, and beneath a threshold of concern (Roche 2013).

Cattle grazing is a significant cause of *E. coli* spikes, but human activities in residential areas or campsites also contribute (Sierra Streams Institutes 2011). Humans often swim or wade in creeks near their campsites, stirring up the sediment at the bottom. *Escherichia coli* attaches itself to the sediment, prolonging the bacterium's life in the water. When the sediment is kicked up, it causes *E. coli* spikes at that location (Smith 2005). Rural residential areas may have the same swimming issues as campsites, but they may also be polluted by debris from roads, oil leaks from motor vehicles, large scale dumping, or shoddy septic systems. It is important to take stock of these sources together, because multiple forms of land use often coexist within close quarters in the same watershed. Forest pasturing meadows, human recreation areas, roads, and vehicles may exist within one hundred yards of each other (Miller et. al. 2010). This can make identifying specific pollutant sources more difficult, necessitating procedures such as *E. coli* DNA tests to verify the source of a particular bacterium in the stream (Stea et. al. 2015). However, observational data is often sufficient for identifying pollutant sources, particularly where land use is less varied (Derlet 2012).

I conducted a six-week study on several streams in the Willow Creek Watershed, south of Yosemite National Park. Specifically, I examined how management of public land affects surface water quality over time and whether current land practices contributed to reduced water quality. To do this, I measured *E. coli* levels in the Willow Creek watershed were to determine whether they fell within the EPA standard limit. I also pinpointed certain sources of pollution such as (a) grazing, (b) recreation, and (c) residency to find the impact of these factors on water quality. I expected to find that *E. coli* levels were below EPA standards and that a combination of cattle grazing, recreation, and residential land use are compatible with the watershed. Furthermore, this study aims to delve into the government policies behind water quality testing, analysis, and response, identifying possible gaps in administrative processes to determine whether current land use practices are sustainable in maintaining good water health.

METHODS

Study Site

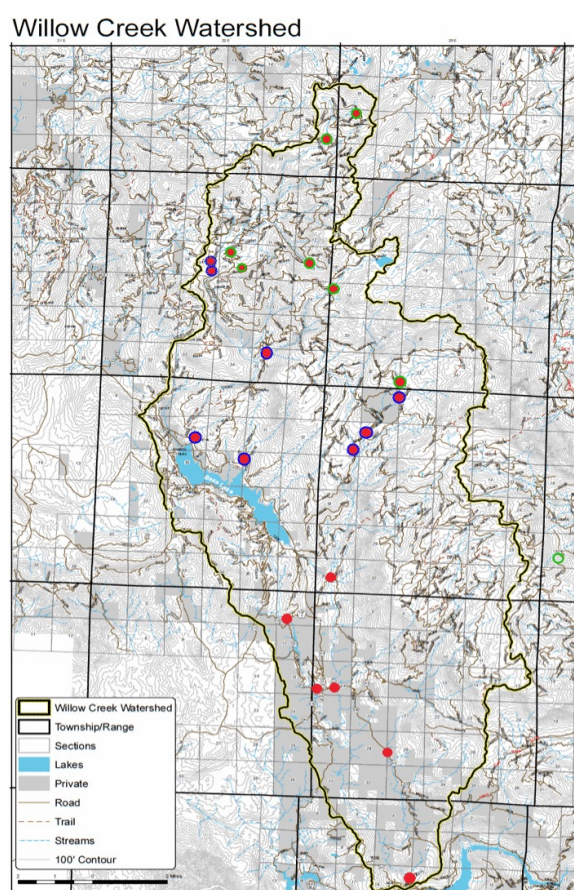


Figure 1. Map of watershed and sample site locations. Locations are color coded based on land use type, with green indicating high elevation meadows, blue indicating recreation areas, and red indicating rural-residential areas.

The Willow Creek watershed in eastern Madera county encompasses small, high gradient streams in the forests of the Sierra Nevada that debouche into Bass Lake and Redinger Lake as they flow farther south and with decreasing elevation. This area includes mountainous meltwater streams and rivers running through oak and shrub-covered foothills. The primary residential areas within Willow Creek are the towns of North Fork and South Fork. To take a representative sample of overall stream health throughout the watershed, my supervisor Rebecca Ozeran, the Livestock Coordinator at the UC Cooperative Extension in Fresno, consulted with a Forest Service employee who recommended several public stream sites near possible contaminant sources.

After visiting each recommended location and determining the accessibility, I narrowed them down potential sites to twenty-one sample locations (Figure 1, Appendix A). These locations

may be categorized as (a) downstream of high elevation meadows, (b) adjacent to campsites, and (c) in residential areas near North Fork or South Fork. After choosing my locations, I proceeded to sample each once per week for seven weeks from the 29th of June to the 7th of August in 2017. There were six samples in total for each site because I staggered the weekly collection. Only the northern half of the samples were collected in week one, all were collected in weeks two through six, and only the southern half were collected in week seven.

Data Collection

When I visited each sample site, I took qualitative, descriptive data of each location to monitor the environmental conditions and the change in those conditions over time. The descriptions included a qualitative visual estimate of stream flow rates (and the difference in flow between sampling weeks), the sample location's proximity to roads, and nearby human and animal activity. For example, I sampled campsites with campers present, recreation areas with past indications of human activity, and stream sites with hoof prints nearby, indicating the recent presence of free range cattle. I also noted the overall environmental condition of each site, marking down if there was litter or cow patties, for example. I took photos of each site, and their locations are listed in with coordinates (Appendix A). These categorical site conditions could be used to help interpret quantitative measurements by indicating a nearby non-point pollution source.

To analyze water quality at each sample site, I used EPA method 1603, a standard filtration and growth method (USEPA 2009). At each site, I collected a 500 mL sealed plastic container of stream water weekly, and stored the samples in a cooler for transportation to the lab. There, I sterilized all our equipment with iodine and prepared to filter our samples. We used Sigma-Aldrich 0.45 um filtration membranes that allowed water to pass through but was small enough to retain bacteria like *E. coli*. With a vacuum pump, I filtered each of our samples through these filtration membranes for 25, 50, and 100 mL volumes. Then I placed the filtration membrane into a petri dish filled with a growth agar that would promote *E. coli* growth and color the bacteria blue. This agar was prepared using powdered casein enzymatic hydrolysate and yeast extract mixed with water (Sambrook 1989). To establish a control sample, I also pumped pre-sterilized water through another membrane.

I incubated the petri dishes at 140 degrees Fahrenheit for 20 to 24 hours, and then counted the number of blue-colored colonies that grew on each dish. One of the reasons I used 25 and 50 mL volumes of sample water for our filtration membranes, despite 100 mL being the standard sample size, was to make sure there would not be so many colonies that they would overlap too much to count in case of a high bacteria level. In the case of the Willow Creek watershed samples, the 25 mL plate would rarely be completely covered. Once we had the counts for each plate, we scaled the ratio of all the counts to Colony Forming Units (CFU) per 100 milliliters, which is the standard unit of measure used for labeling *E. coli* presence (Dufour 1981).

Data Analysis

To determine whether the water quality was at a healthy level for human use, I calculated the geometric mean of each sample's CFU/100 mL. The geometric mean is expressed as

$$y = \text{nth root of } y_1 * y_2 * y_3 \dots y_n.$$

The geometric mean is a combination of sample colony counts that estimates the overall health of the sample location over the sampling period. It is the EPA standard for water quality benchmarks, and a geometric mean of less than 100 CFU/100 mL indicates acceptable water quality (USEPA 2012). The reason we use the geometric mean instead of an arithmetic mean is because it better computes an average in numbers of vastly differing numerical values. Arithmetic means are highly sensitive to outliers, while geometric means take the other values into greater consideration, and do not inflate the importance of outliers. This metric makes the geometric mean excellent for EPA 1603 testing, because it is common to find both very low and very high CFU/100 mL counts at the same sample site. It is a good indicator of whether a stream site needs to be closed.

Besides the geometric mean, the EPA uses the statistical test value threshold (STV) to determine water health, expressed as

$$\log(STV) = \text{avg}(\log \text{ values of sample results}) + 1.282 * \text{std}(\log \text{ values of sample res.})$$

The statistical threshold value, which is 320 CFU/100 mL, represents the 90th percentile of the water quality distribution, and it should not be exceeded by more than 10% of the samples taken within a month (USEPA 2012). This extra constraint indicates locations with poor water quality that experience extreme spiking in bacterial indicator counts, but may have low CFUs most of the time.

RESULTS

Data Collection

The average number of colony forming units of *E. coli* for every 100 mL of stream water measured within the EPA and California Water Board's acceptable maximum limit of 100 CFU/100 mL for all sample sites. The geometric mean for each site was below the threshold of 100 CFU/100 mL as well. Some individual samples extend above one hundred CFUs at Chipmunk Meadow, above Gaggs Campground, below Soquel Campground, and below Whisker's Campground (Figure 2).

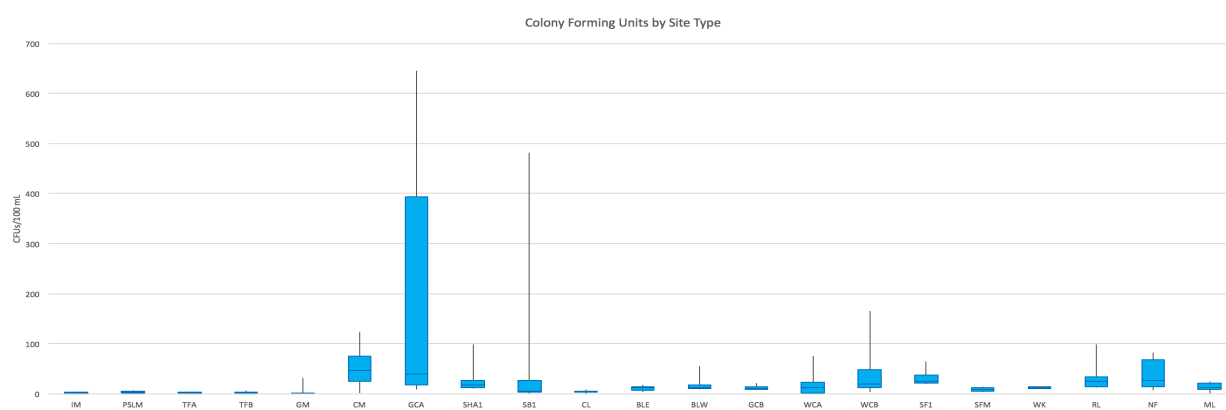


Figure 2. Overall *E. coli* concentrations for 125 stream water samples collected from 21 sample sites between June 29th and August 7th, 2017. The bottoms and tops of the shaded boxes are the 25th and 75th percentile of data, the horizontal line within the shaded box is the median value, and the ends of the vertical lines are the maximum and minimum values. This box plot displays averages and outliers with clarity, opposed to a bar graph.

Of the sites with samples above 100 CFU/100 mL, Gaggs Campground and Soquel Campground had colony counts above the EPA's 320 CFU/100 mL maximum STV for 10% of the total samples. Gaggs Campground, a pasture site downstream of a high elevation meadow, had a geometric mean of 40 CFU/100 mL, but outliers extending to 1.56 and 1.96 times the STV limit. These outliers occurred during the last samplings in late July and early August, as water levels decreased. The other meadow sites maintained sample counts below 100 CFUs, except for an exceedance below the STV in Chipmunk Meadow (Figure 3a). Soquel Campground, a recreation site, had a geometric mean of 29 CFU/100 mL, but an outlier 1.53 times the STV limit. The spike at Soquel was on July 18th, and the only other recreation site exceeding 100 CFUs was below Whisker's Campground on August the 7th (Figure 3b). Rural-residential sites were more consistent in colony counts, which all stayed below 100 CFU/100 mL, and did not vary so extremely week by week (Figure 3c).



Figure 3. *E. coli* concentrations for each sample date separated by site type. a. *E. coli* concentrations for 42 water samples from high elevation meadow sites. b. *E. coli* concentrations for 48 water samples from recreation sites. c. *E. coli* concentrations for 36 water samples from rural residential sites.

We also collected qualitative data for each sample that we took over the seven weeks, monitoring physical observations of our sites over time. These observations included stream flow levels, water depth, vegetation health, and signs of animal presence (Appendix B).

Policy Implementation for Unsafe Recreation Areas

I conducted qualitative research about government policies regarding the shutdown or warning systems in place for recreation areas where *E. coli* has been tested at unsafe levels. I found that these policies varied both by department and by government management level: county, state, or federal. The counties all lacked policies of their own with regard to metric water quality standards, and deferred to state standards. County governments also only responded to water quality exceedances on case-by-case basis, while state and federal governments had consistent and standard responses.

Table 1. This Policy table depicts the different levels of government that have authority over the Willow Creek Watershed, the policy they refer to for quality analysis, the *E. coli* standards within that policy, and the response to tested areas that exceed those *E. coli* standards (including whether those responses are consistent or unreliable).

Government Agencies	Policy Reference	<i>E. Coli</i> Standards ^{1,2}	Response to Exceedances ^{3, 4, 5}
Forest Service	Refers to Federal Ordinances	GM < 126 CFU/100 mL STV < 410 CFU/100 mL	<i>Consistent</i> Road closures; site closures; signage
Madera County	Refers to State Ordinances	GM < 100 CFU/100 mL STV < 320 CFU/100 mL	<i>Case-by-case</i> Remediation; public outreach; signage
Mariposa County	Refers to State Ordinances	GM < 100 CFU/100 mL STV < 320 CFU/100 mL	<i>Case-by-case</i> Remediation; public outreach; signage
Merced County	Refers to County and State Ordinances	GM < 100 CFU/100 mL STV < 320 CFU/100 mL	<i>Case-by-case</i> Remediation; public outreach; signage
Central Valley Water Board	Refers to State Ordinances	GM < 100 CFU/100 mL STV < 320 CFU/100 mL	<i>Consistent</i> Remediation; site closure; public service announcements

[¹USEPA 2012, ²California State Water Board 2018, ³SWRBC 2010, ⁴Merced County 2012, ⁵Code of Federal Regulations 2007]

DISCUSSION

This Sierra Nevada case study sought to determine the water quality of the Willow Creek Watershed for forested, recreational, and rural residential land use types. I wanted to determine the effect of cattle pasturing on bacterial water contamination in forest stream sites near meadows. Willow Creek water quality generally met health and safety standards, indicating that cattle grazing, recreation, and urban settlements can be compatible with stream health. The study also raised questions about monitoring the causes of *E. coli* contamination in streams and the process for policy management in recreation areas. After *E. coli* exceedances are detected, responses vary between recreational site closure, signs, and public service announcements. However, these responses are not implemented on a consistent basis for county governments, which often rely on nearby state and federal agencies to monitor water quality. Furthermore, the Central Valley Regional Water Board, which is responsible for more surface water monitoring than any other government agency, generally only monitors large rivers, and not the high elevation tributaries that feed into them (SWRBC 2010).

Willow Creek watershed case study

Water samples had low and consistent *E. coli* levels with the exceptions of spikes at a few of the sites. In each instance, unusually high *E. coli* colony counts corresponded with a visible disturbance of sediment, hoof prints, and/or crushed vegetation in and around the stream. The site below Soquel Campground spiked to 498 CFU/100 mL in the third week, when campers were present at the site, wading in the stream and stirring up the sand. Furthermore, the two high colony counts at Gaggs Campground corresponded with the last sampling weeks in late July and early August, and this is the time that I observed hoof prints, flattened vegetation, and cow pats around the sampling area.

The reasons underlying the *E. coli* spikes are important to consider because most *E. coli* cells are indicators, and therefore correlate to, but do not cause the presence of other harmful bacterial pathogens (Roche 2012). However, *E. coli* is not always a perfect indicator of harmful microbial pathogens because it can live suspended in water for a long time by attaching itself to sediment or algae (Field and Samadpour 2007). This means, for example, that if fecal matter

containing *E. coli* and *Salmonella* entered a stream, the *E. coli* could attach itself to sediment and outlive the *Salmonella*, indicating a pathogen that is no longer there. However, *E. coli* is not useless as an indicator bacteria because (a) a stream that has not been stirred up will not have sediment-suspended *E. coli* in the sample, and (b) sediment provides a surface of attachment for other harmful pathogenic bacteria as well as *E. coli*, meaning stir-ups are still a health hazard worth monitoring (Perlman 2016). Furthermore, *E. coli* fulfills an important human health component because it is a good predictor of human gastro-intestinal illnesses (USEPA 2012). Whether *E. coli* enters a stream from an external source, such as fecal matter from cattle, or if it is stirred up from sedimentation is important to consider. The former is a more concrete predictor of disease because pathogens are very likely suspended in the water with the *E. coli*.

Regarding the effect of cattle presence, I obtained water samples before and after the pasturing season began on July 9th, and by sampling for a total of 6 weeks from June through early August. I wanted to ascertain whether there was a difference in *E. coli* before and after the pasturing began, and this difference was apparent at Gaggs Campground, where the presence of cattle increased the colony counts from single digits to several hundred. I did not observe cattle at other high elevation meadow sites, and two of the sites were impacted by foresters removing diseased trees, driving off animals in the area. Also, several ranchers did not bring their cattle up as early as July 9th, but instead waited until a few weeks into the season. If I had continued sampling further into the year, it is possible that I would have observed the effects of more cattle being pastured, as exemplified by the Gaggs Campground site.

Although the *E. coli* levels I sampled in the Willow Creek watershed were all below the geometric mean, two sites exceeded the STV limit. The importance of the STV exceedances in this case study may be difficult to interpret. I only took six samples per site, meaning that one sample that exceeds the STV threshold would push the site above the ten percent threshold for unhealthy water quality (USEPA 2012). I reasoned that a larger number of samples would need to be taken for the STV value to have bearing in a water health assessment. However, upcoming California policy in the 2018 proposed final for Part 3 of the Water Quality Control Plan for Inland Surface Waters states that a six week long, once per week sampling period is the common standard for water testing. It also states that the STV should be calculated for the number of samples taken in one month (SWRBC 2010). From this, it seems that STV calculations are used for sites with four or five samples, and that it is standard for one sample above 320 CFU/100 mL to indicate

poor water quality, even if the geometric mean is below 100 CFU/100 mL. If this is the case, then Gags and Soquel Campgrounds both fail their STV requirements even though they have passing geometric means.

Government guidelines and practices

Government monitoring of, and response to, potential water quality issues in recreation areas is difficult to generalize, because water policies change based on the branch managing the watershed and the level of government enforcement, from federal to state to county. The counties making up the Willow Creek Watershed are Madera, Mariposa, and Merced. Many county governments do not have municipal recreational health regulations, but instead defer to federal standards. In this case, both Madera and Mariposa counties defer to state standards for recreation areas like parks, while Merced County does have one ordinance, 1813, banning swimming in parks outside of designated areas. However, this ordinance does not mention water quality testing, and it is unclear if the swimming ban is in place for environmental reasons or to prevent drowning accidents (Merced County 2012). Because Madera and Mariposa Counties refer to state water standards, the State Water Board would apply the same threshold of 100 CFU/100 mL to surface waters there as I describe in my case study. There is no description, however, of how these standards would be monitored for camp sites. Part 3 of the Water Quality Control Plan states that the only non-point source pollutant monitored by the state is storm water runoff (California State Water Board 2018). Although it is not specifically stated in the Water Quality Control Plan, the Central Valley Water Board does monitor water quality for recreation areas, but only on big rivers in low elevation areas (SWRCB 2010).

Other agencies within these counties that work with water quality in Willow Creek include the US Forest Service, which is the agency that monitors the forest sites and several of the recreation sites from the case study. The Forest Service, like Merced County, takes a precautionary approach for the safety of campers and preservation of stream health by stating that campers are not to enter any body of water except those particularly marked for swimming (Code of Federal Regulations 2007). This may function both to decrease injury liability and lower the necessity for water safety testing. Yet anyone who has gone camping knows that this rule is not generally enforced or obeyed. The Forest Service produces signs that explain these recreational rules and

can be placed on camp site notice boards, but it is their policy not to put these signs up unless rule-breaking has been a problem in the past (USDA 2013). Furthermore, there is no official procedure on monitoring adherence to these rules.

The monitoring methods of the Forest Service are not fully explained through their documentation, but they do have special campsites closure procedures in place for several causes, including public health and safety (Code of Federal Regulations 2007). Common causes for camp site closures include unsafe conditions such as falling trees, flooded areas, bank collapse, or site construction (USDA 2018). Although there is no documented Forest Service procedure for closing a campsite because of bacterial contamination, an impact of this type would constitute a public health issue and merit response. The Forest Service often depends on an independent agency or the State Water Board to monitor for stream biohazards and be informed of when a campsite should close (USDA 2013). Overall, several government agencies handle public water quality, and they often fall back on each other to fill in procedural gaps. Those grey areas in policy are where employees use their judgement and insight. I attempted to conduct an interview with a State Water Board and Forest Service employee to inform the conclusions of this study, but was not successful in gaining a response. Such an interview would be an important continuation of this research.

Limitations and Future Directions

Water quality for any given area has the potential to change ephemerally, particularly when the water quality is dependent on non-point source pollutants, such as cattle or storm water. Because of the tendency of water quality to fluctuate, it is normal to conduct sampling over six weeks (as with my sampling) to determine water quality averages. However, it would have been interesting to extend my case study beyond the standard six-week sampling period and observe changes throughout the summer, because of the increased cattle pasturing and the spikes in the last sampling weeks of Gaggs Campground. This change is what complicates policy implementation, and provokes debates on different monitoring methods and the sensitivity of the tests performed. Furthermore, government policy has limited resources for quality testing, and resources are dedicated to more heavily-trafficked areas such as beaches and large rivers (Haile et. al. 1999). The Forest Service attempts to solve water quality issues with a policy keeping campers from swimming or wading, but it may also be helpful to provide campers with information about

pollutant sources. It is useful knowledge that stream areas with murky water, animal prints nearby, or flattened banks should be avoided as a precaution. The Forest Service and the National Park Service are also taking steps to relocate camp sites farther away from the banks of streams to preserve stream bank integrity (NPS 2013). This approach is another way to solve the recreational water quality problem in forested natural areas.

Beyond the scope of this study, it would be valuable to gather information on policy implementation through survey data on interdepartmental government policy and practice. Speaking to environmental professionals, noting their methods of selecting which watersheds to sample, and ascertaining their interpretations on implementing laws would fill the gaps left in government ordinances.

Conclusions

My case study with Rebecca Ozeran and the UC Cooperative Extension found that 19 out of our 21 sample sites fell within EPA guidelines for bacterial indicators, meaning that land use practices during the sampling period were compatible with land use practices in Willow Creek. Delving into policy, most gaps in the government rules and regulations are related to testing and monitoring water quality. The State Water Resources Control Board has an excellent water quality monitoring and response system, but does not include bacterial contaminants from non-point sources such as cattle grazing in their most recent legislation on impaired water bodies (California State Water Board 2018). The Forest Service, similarly, has regulations for campsite closure, but none referring directly to bacterially impaired water bodies (Code of Federal Regulations 2007). More specific wording in these government ordinances would raise awareness and attention toward *E. coli* contamination from non-point sources, including in mountainous areas that are not heavily monitored. Furthermore, county health departments would benefit from interdepartmental collaboration, to increase efforts toward local water health. Public signs or pamphlets would be helpful to improve understanding of water contamination for campers, educating them on avoiding water bodies near observable non-point source pollutants. These efforts could be a step toward better management of California's watershed and better human health.

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APPENDIX A: Table of Coordinates**Table A.** This table depicts the exact coordinates of each sample site in the Willow Creek watershed. The table lists the names of the sample sites, and each of their latitudes and longitudes.

Location Title	Latitude	Longitude
Bass Lake East	37.325901	-119.54345
Bass Lake West	37.3348503	-119.56953
Chilkoot Lake Campground	37.3710823	-119.53494
Chipmunk Meadow	37.3991408	-119.50442
Gaggs Campground Above	37.3628044	-119.47157
Gaggs Campground Below	37.3542633	-119.4707
Greys Mountain	37.4087791	-119.51625
Iron Mountain	37.4734612	-119.49494
Manzanita Lake	37.2583504	-119.52306
North Fork	37.2286008	-119.50656
Polk Salt Log Meadow	37.461895	-119.50983
Redinger Lake	37.150322	-119.46043
Soquel Below	37.4064026	-119.56259
South Fork	37.2766228	-119.50228
South Fork Motel	37.2301521	-119.49806
Soquel Campground Above	37.4087524	-119.56383
Texas Flat Above	37.4069339	-119.54974
Texas Flat Below	37.4121132	-119.55372
Whiskers Campground Above	37.3382149	-119.48637
Whiskers Campground Below	37.3321075	-119.49305
Whiskey Creek	37.203277	-119.4721

APPENDIX B: Observational Table

Table B. This observational table shows notes on site condition for each sample taken at every sample site. Each site is labeled with its abbreviation, full name, and a description of its land use type. The samples are numbered in the order that they were taken.

Site	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
IM (near Iron Mountain; "wilderness" site, above road)	Clear, rapid flow; no livestock or rec	Clear, steady flow; no livestock or rec	Clear, but slower and lower flow than previous week; no livestock or rec	Water nearly flooding road, diversion by debris; clear, slow flow; no rec, signs of livestock in meadow below	Nearly dry, very slow, but clear; no livestock or rec on site, evidence of livestock in meadow below	Dry. Evidence of cattle nearby.
PSLM (below Polk Salt Log Meadow, key grazing area)	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid flow, slightly lower than previous week; no livestock/rec	Rapid, clear flow; hoof traffic, possible cattle and deer, some rec nearby	Clear, rapid, shallower; no livestock or rec, hoof prints present on road	Clear, rapid, shallower still; old hoof prints on road, no livestock at water, no rec
SHA (Soquel camp host area, "above" the camps)	Clear, steady flow; host present	Clear flow; host present, dog on site	Clear, rapid flow; host on site	Clear, steady, but lower and meandering; host absent	Clear, rapid; new host (no dog, temporary outhouses)	Clear, steady, but slower and shallower; host on site
SB (Soquel campground, below all camp sites)	Clear, steady flow; 4 campsites occupied	Clear flow; ~ 8 vehicles/campsites occupied	Clear, slow and steady; 12-15 vehicles at campsites, several dogs	Steady, clear; all camps taken, 13 vehicles, garbage; people wading	Steady, shallow, slow; 6 vehicles at 4 camp sites, people on stream bank	Slow, shallow but still clear; people in water; 8-9 vehicles, all camp sites occupied
TFA ("Above" key grazing area at Texas Flat)	Clear, slow flow; no livestock or rec	Clear flow; no livestock or rec, but active logging	Clear, steady, rapid; no livestock or rec, logging still nearby	Clear, steady flow; new spring/upwelling on bank; no livestock/rec	Clear, rapid; no livestock or rec; logging still nearby	Clear, rapid, shallower; upwelling flowing; no livestock/rec, woody debris on banks
TFB (Below key grazing area)	Clear, rapid flow; no livestock or rec, but	Clear flow (sampled above stagnant area); no livestock or	Clear, steady, slightly slower than	Clear, rapid; no livestock, logging	Clear, rapid; 2 cows downstrea	Clear, rapid, lower than previous week; no livestock/rec

at Texas Flat)	logging operation	rec, logging equipment near	before; no livestock or rec	traffic still evident	m of site, no livestock or rec on site	
GM (Near Greys Mountain, upstream of culvert, nearby grazing area)	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid, shallow; veg flattened on both banks, suggesting livestock, no rec
CM (Chipmunk Meadow, off Central Camp Rd, upstream of culvert; grazing area)	Clear, slow flow; no livestock or rec	Shallow but steady flow; culvert blocked by woody debris; no livestock or rec	Clear, but lower flow than previous week; culvert still blocked; no livestock or rec	Clear, steady, low flow; culvert still blocked; no livestock or rec	Clear, shallow flow; culvert still blocked; no livestock or rec	Steady, clear, shallow; culvert still blocked, accumulating sand and gravels; no livestock/rec
CL (Chilkoot Lake camp, upstream of bridge and camp; campground closed)	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock or rec	Clear, rapid flow; no livestock, signs of rec at bridge/sample site	Clear, rapid flow; no livestock, but rec evident (trash); USFS truck on site	Clear, rapid, still fairly deep; recent rec downstream, no livestock	Clear, rapid, lower than previous week; no livestock/rec
BLE (Pines Creek, leading into Bass Lake, east site)	Clear, steady flow; no livestock or rec, but vehicle traffic on Rd 274-	Clear, rapid flow; possible livestock, signs of rec - used campfire	Day use area closed; wood pallets in water; clear, steady flow, no livestock, possible rec	Pallets still present, water lower; clear, steady; no livestock, people upstream	Clear, steady, shallow; ladybugs abundant; no livestock/rec	Clear, steady, low; pallets still in water; no livestock or rec
BLW (North Fork of Willow Creek, leading into Bass Lake, west site)	Clear, steady flow; no livestock, 3 rec vehicles on site	Clear, rapid; no livestock, 3 vehicles at trail head	Rapid, clear flow; no rec present but signs of recent activity, no livestock	Rapid, high, clear flow; lots of rec on site (2 vehicles, ~8 people), no livestock	Clear, rapid, fairly deep; 2 vehicles and people rafting, no livestock	Clear, rapid; 1 vehicle present, trash in water (rec), no livestock

GCA ("Above" Gaggs campground , just below a grazing meadow)	Clear, slow flow; banks eroded; algae developing downstream of sample location; no livestock/rec	Clear, steady flow, algae still downstream; no livestock or rec; noticed "rip rap" (boulders) placed on far bank upstream	Algae still growing downstream; clear, steady flow; no livestock/rec	Clear, steady, algae present on substrate; cattle recently in area (smell, hoof prints and cow pats)	Clear, steady; algae still present; hoof prints on road, vegetation by water flattened (livestock), no rec	Clear, steady; hoof prints and fresh cow pies on road, vegetation flattened; upstream meadow no animals, no rec
GCB (Blw Gaggs campground , steeply downhill from road; above Central Camp)	Clear, rapid, and deep; no livestock or rec	Clear, rapid; no livestock but smelled scat, saw some evidence of rec upstream	Clear, rapid, slightly lower than previous week; no livestock/rec	Steady, clear, fairly deep; riffles forming from sand + woody debris, algae; recent rec, no livestock	Clear, steady, slow; algae continues to accumulate , footprints on sandbar (rec) but no livestock	Clear, steady, slow; algae accumulating; footprints and moved log (rec), no livestock
WCA (Abv Whiskers, blw Central Camp; downstream 7S02 bridge)	Clear, rapid; no livestock or rec	Clear, steady; no livestock or rec	Clear, rapid, deep; no livestock/rec	Clear, rapid, deep; signs of rec (fishing), no livestock	Clear, rapid, still fairly deep; recent rec (trash) but no livestock	Clear, steady, slower; no livestock/rec
WCB (Below Whiskers campground , park follow trail to water upstream of bridge)	Clear, rapid; no livestock, 2 vehicles present at campground	Clear, rapid; 3 camping groups including 1+ dog	Clear, rapid; evidence of recent rec, no livestock	Clear, rapid, shallower than previous week; campground empty, no livestock	Clear, rapid, shallower than previous week; campground empty, no livestock	Clear, rapid, getting shallower; camp empty, bagged trash at camp sites, evidence of livestock
ML (North Fork of Willow Creek near Manzanita Lake; lots of trees in creek bed)	Rapid, meandering , deep and shaded; no livestock, evidence of recent rec (trash)	Rapid, deep and slightly murky; no livestock, campers on site (not an official campsite)	Rapid, deep, slightly murky; lots of foot traffic evident and 2 vehicles on site, no livestock	Rapid, clear, but lower than previous week; lots of trash/recent rec, no livestock	Clear, rapid, lower - sampled 5m upstream for access; campfire and trash, basket/trap submerged	Clear, rapid, lower than previous weeks; 1 vehicle (1 person +1 dog) and submerged trap on site
SF (South Fork of Willow Creek, off	Clear, steady; no livestock or rec	Clear, slow moving above rapids; rural residences and	Slow, clear flow; innertubes + tire treads near water's	Steady, slow, shallow, water receding;	Shallow, steady, slow; no livestock or rec	Steady, shallow; innertubes and new footpath by water, no livestock

Willow Canyon Dr)		stray dogs, no livestock	edge (rec), no livestock	recent rec, no livestock		
NF (Downstream of Rd 225 bridge east of the BL Ranger Dist., west of Rd 274)	Rapid, but low visibility; no livestock, small trails and trash suggest recreation	Deep and murky; no livestock, still abundant trash; weedy area	Steady but slow, deep, and slightly murky; no livestock, same signs of rec as before	Steady, deep, slightly murky, and lower than last week; recent rec, no livestock	Clear, slow, steady; trash still abundant, no livestock	Slow, steady, deep; some algae growing on submerged branches; recent rec, no livestock
SFM (Downhill from South Fork Motel (rural residential area), South Fork of Willow Creek)	Steady, clear flow aside from sediment downstream; no livestock, metal barrel downstream	Clear, slow, and shallow; no livestock, but signs of rec (trash)	Sample site moved to under bridge due to lower flow; tent, clothing and garbage on banks; no livestock	Tent still under bridge but closer to water; steady, slow flow, shallow and clear; no livestock	Clear, slow, shallow; tent gone, but trash remains; no livestock, deer hoof prints	Slow, shallow; trash still abundant, no livestock
WK (Below bridge on Rd 225 crossing Whiskey Creek (rural residential))	Clear, rapid flow; no livestock or rec; rural residences; woody debris	Clear, rapid; no livestock or rec	Clear, rapid, still fairly deep; no livestock/rec	Clear, rapid; no livestock, some rec (trash)	Clear, rapid; recent rec possible (footprints), no livestock	Clear, steady; recent rec (trash), no livestock
RL (Whiskey Creek into Redinger; concrete below sample point, control flow)	Clear, rapid flow; no livestock or rec on site but campers at campground east of site	Rapid, slightly murky; no livestock/rec	Rapid, deep flow; no livestock/rec	Clear, rapid, water level flowing below concrete (reduced water flow); no livestock or rec	Lower flow, sampled from eddy because no longer reach rapid flow area; no livestock/rec	Slow and steady; no livestock/rec