Sources of *E. coli* and Mitigation of *E. coli* in the American River

Thesis

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Abstract

Escherichia coli (*E. coli*) is a fecal bacterium normally found in animals' intestines. In our intestines *E. coli* makes vitamin K which helps clot our blood. When *E. coli* reproduce in our intestines, some of the resulting *E. coli* will have mutated DNA. The mutated *E. coli* then produce toxins capable of making humans sick. All around the world *E. coli* has found their way into public waterways such as lakes, rivers, coastal ocean, bays, and ports. *E. coli* is an enteropathogen that is an indicator organism used to determine fecal contamination in waterways. The U.S. Environmental Protection Agency (EPA) has established acceptable levels of *E. coli* in the waterways based on the likelihood of associated illness rates. The Lower American River in Sacramento, California has exceeded the maximum EPA established *E. coli* levels since formal testing was done in 2011. Over the last 3 years Tiscornia Beach, a testing site on the Lower American River, has yearly average *E. coli* counts exceeding the EPA maximum by three times and a third of the weekly counts are eight times above the maximum EPA acceptable level. The origin of the *E. coli* in the Lower American River has not yet been determined by the Central Valley Water Board. Significant evidence from similar *E. coli* polluted waterways would lend one to believe that the *E. coli* in the Lower American River originated directly from human defecation in the waterways by the homeless who live near the American River, from urban sewage overflows, from contaminated sediments, and/or from migrating and non-migrating birds. The least likely source of the *E. coli* would be leaky septic tanks or dogs along the American River. The city of Sacramento and the Central Valley Water Board must make a mitigation plan to bring the *E. coli* counts in the Lower American River below the acceptable standards. There are mitigations models to reduce the *E. coli* in the American River that have been used and studied all around the world. The most promising

mitigation models to help restore the Lower American River to a more pristine and safe recreational environment are to reduce the direct sources of *E. coli* by improving the stormwater filtering system or increasing access to riverfront bathrooms, adding ecosystem services along the edge of the river, like wetlands, canals, riparian habitats, and reservoirs to capture, remediate, and clean the water before the water enters the river again from the original sources, and/or cleaning the water and sediment that currently has high levels of *E. coli*.

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Background

Without water humans would die. Humans are dependent on water for osmotic homeostasis in our body, drinking, cooking, food sources, and recreation. Water makes up 71% of the earth's surface, only 3% of that water is fresh water. Sixty eight percent of the freshwater is locked up in glaciers, ice caps, and permafrost, while just over 30% of the freshwater is ground water. In the end only .3% of the 3% fresh water on earth is usable drinkable water and useable recreational water (National Geographic : Educator's Guide, 2021). We rely on this small amount of fresh water for our survival, our everyday activities, and our entertainment, yet with our increased population, urbanization, and homeless camps our water supply is becoming polluted by many toxins and living pathogens.

One pathogen that has invaded all our water systems is *Escherichia coli,* or *E. coli*. *E. coli* is a fecal coliform bacterium that is found in the digestive system of humans and animals and is excreted out of our bodies with the feces. Most *E. coli* are not pathogenic, but one strain, *E. coli 0157:H7,* has mutations in its DNA that produces toxins which can cause severe illnesses in humans. *E. coli 0157:H7,* when ingested, can cause mild diarrhea, severe watery, bloody diarrhea, cramping, headache, kidney failure or even death (Brazier, 2017). Both the Environmental Protection Agency (EPA) and more specifically, the California Valley Water Board (CFWB) have established a maximum acceptable level of *E. coli* in waterways.

Our local American River is one waterway affected by increased population, urbanization, and homeless camps which has resulted in increased levels of *E. coli* in the river. The Central Valley Water Board has been collecting data on the amount of *E. coli* in the American River at multiple locations for the last 3 years. They found the amount of *E. coli* in the Lower American River reaches levels close to 3000 MPN/100 mL (Central Valley Water

District, 2021). This is nine times above the highest acceptable level of 320 MPN/100 mL for California waterways (EPA, 2015). MPN or Most Probable Number (MPN) is a standard unit used to report estimates of fecal bacteria concentration in water. The water pumped out of the river and used for drinking water is well treated to kill the *E. coli* before reaching the public. The real problem the Lower American River is used regularly by millions of people for recreation. At Discovery Park and Tiscornia Beach families set up picnics, BBQs, wade in the river, swim in the river, and boat in the river. The high *E. coli* levels in the Lower American River are a serious health and safety issue for the public using the river here in the Sacramento area.

The objective of this paper is to address the effects of *E. coli* on humans, sources of *E. coli* in the Lower American river, and the possible mitigation methods to reduce the increased amounts of *E. coli* in the Lower American River. A plan to mitigate the *E. coli* levels in the lower American River by the CFWB, would also be a plan to create a safe aquatic environment for the recreational use of the waterway.

Health Effects of the Toxic *E. coli O157:H7*

Humans, mammals, birds, and fish feces all contain fecal bacteria, often called coliform bacteria. Up to 99% of all coliform bacteria in feces are *E. coli* (Lewis, 2019). *E. coli* bacteria has hundreds of different strains ranging from harmful to non-harmful. The human stomach and intestines typically harbor a non-harmful symbiotic strain of *E. coli* that eats our digested food, produces our gas we call flatulence, and produces Vitamin K to help our blood clot.

The *E. coli* in our intestines are not inherently pathogenic. *E. coli's* pathogenic qualities stem from their rapid reproduction and DNA mutation rate. *E. coli* reproduce by doubling every 20 minutes at ideal conditions (Science Learning Hub, 2014). At this rate one *E. coli* can produce 2^{36} or about 68,719,476,736 *E. coli* in 12 hours. With a mutation rate of 1 mutation per 10^{10} base pairs, and the standard reproduction rate, every base pair could mutate 30 times in 30 hours (Pray, 2008). The rate of *E. coli* reproduction and mutation may result in a pathogenic *E. coli* called *E. coli 0157:H7* (Minnesota Department of Health, 2009). *E. coli 0157:H7* have mutations in the DNA that cause proteins to be made disrupting normal metabolic functions and results in pathogenic bacteria (Donnenber & Whittam, 2001). The *E. coli 0157:H7* produces toxins that damage the lining of the small intestine. When even small amounts of *E. coli 0157:H7* are introduced into the stomach through drinking a contaminated source of water, the resulting symptoms may vary from mild diarrhea to severe watery or bloody diarrhea, cramping, headache, and hemolytic uremic syndrome which can lead to kidney failure or even death (Center for Disease Control and Prevention, 2021).

EPA Clean Water Standards

Testing for fecal coliform bacteria in a water source is used to monitor general water quality. The EPA has established standards for water quality in all freshwater and marine waterways in the United States. The EPA establishes acceptable levels of *E. coli* based on the likelihood of associated illness rates. The EPA's recommended acceptable level of *E. coli* in freshwater with an estimated illness rate of 36/1000 is no greater than the geometric mean (GM) of 125 MPN/100 mL or the statistical threshold value (STV) of 410 MPN/100 mL. The STV is a value that should not be exceeded more than 10% of the time. A second possible EPA recommendation is when the estimated illness rate is 32/1000. In this case the GM is 100 MPN/100 mL and the STV is 320 MPN/100 mL (EPA, 2015). The CFWB has determined that an *E. coli* count of above 320 MPN/100 ml is detrimental to human health.

American River *E. coli* Data

There is varying amount of *E. coli* in the American River in the Sacramento Area, anywhere between 10 – 3000 MPN/100 mL at different spots in the river and at different times of the year (Central Valley Water District, 2021). The CFWB has been collecting *E. coli* amounts found in the American River at 10 different sites from the Sunrise Bridge to Tiscornia Beach for the last three years. (Figure 1). For the sake of this paper, four testing sites will be compared. The four sites are, site #1 Tiscornia Beach, site #2 Camp Pollock, site #3 Paradise Beach, and site #4 Sunrise Bridge (Figure 1).

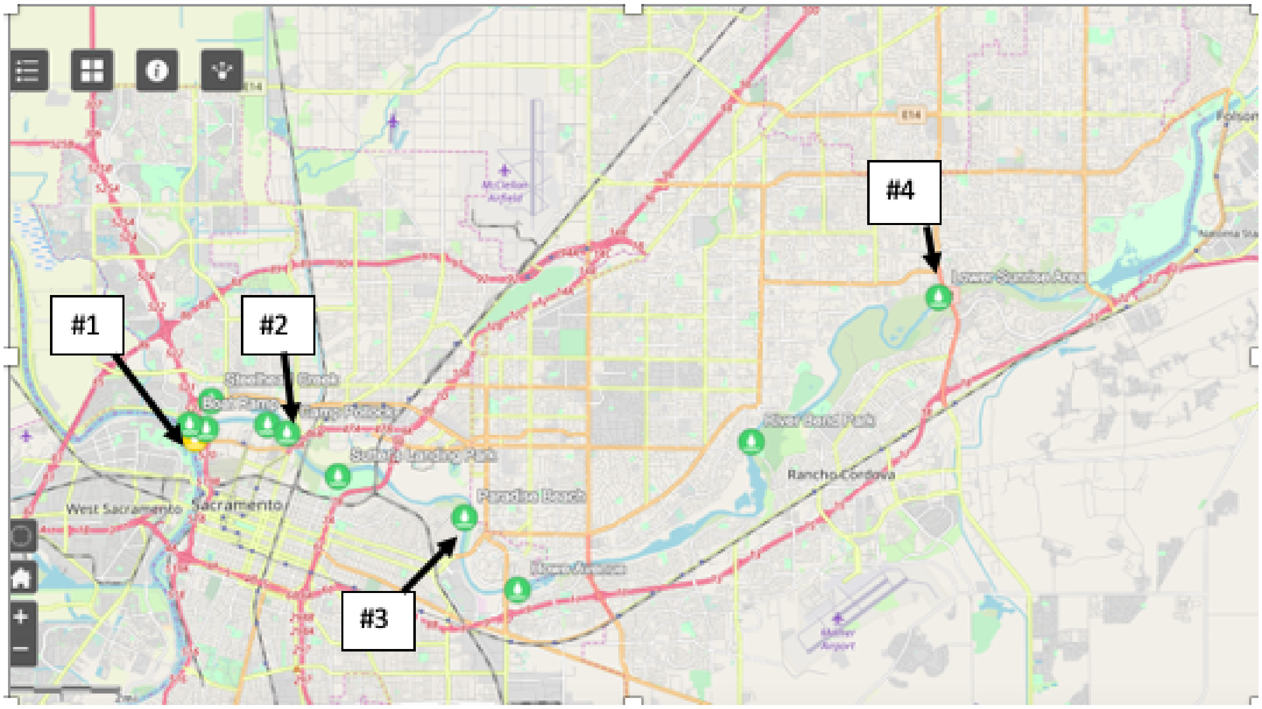

Figure 1: *E. coli* Testing Sites. The green circles identify 10 sites of *E. coli* sampling. For the purpose of this paper, sites #1- 4 represent the 4 testing sites that will be compared (Central Valley Water District, 2021).

In 2019 and 2020 respectively, the average amount of *E. coli* at Sunrise bridge was 41.2 ±6.2 MPN/100 mL and 102.9 ± 70.4 MPN/100 mL. The differences between 2019 and 2020 at Sunrise Bridge is that they have been doing some major construction there, rebuilding the fish hatchery. At Paradise Beach the *E. coli* counts in 2019 and 2020 were 45.0 ± 8.8 MPN/100 mL and 50.2 ± 1.7 MPN/100 mL. At Camp Pollock the *E. coli* counts for 2019 and 2020 were 82.4 ±14.7 MPN/100 mL and 90.0 ± 35.7 MPN/100 mL. At Tiscornia Beach the *E. coli* counts for 2019 and 2020 were 675.9 ± 124.2 MPN/100 mL and 782.5 ± 136.7 MPN/100 mL. (Figure 2) (Whitford, 2020).

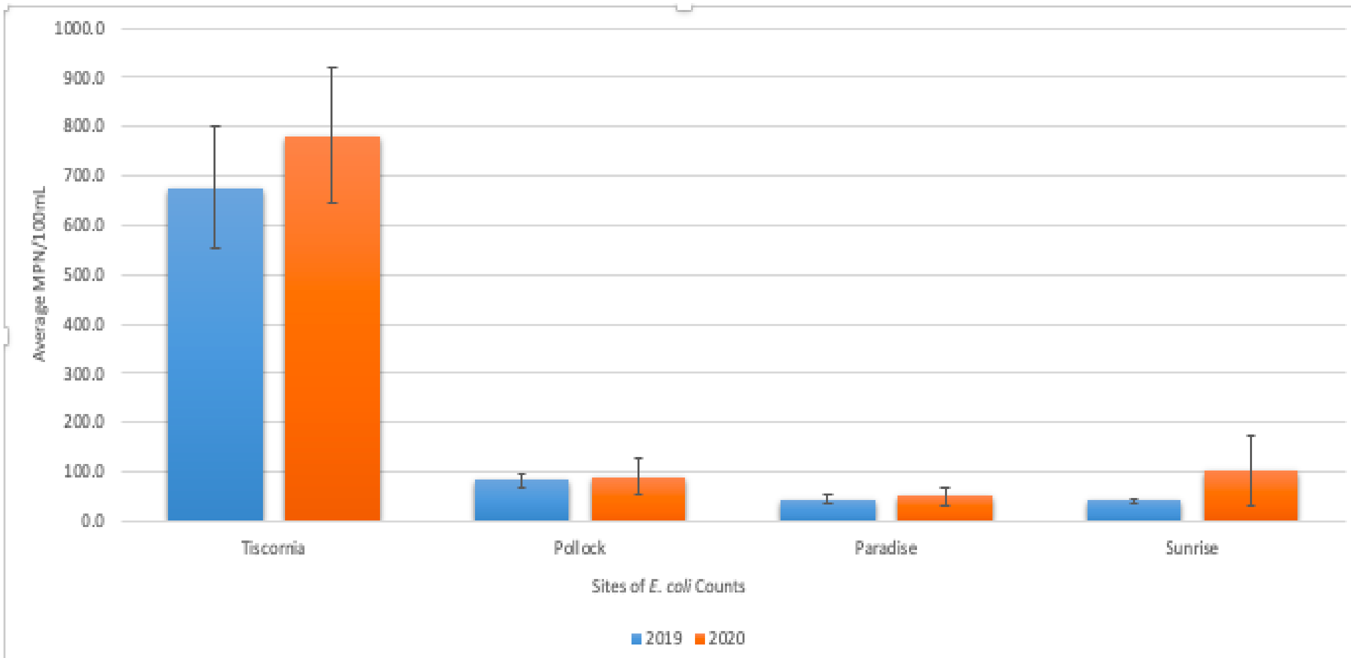

Figure 2: The Average *E. coli* Counts. The average *E. coli* counts taken every week in 2019 and 2020 at 4 different testing sites along the American River (Whitford, 2020).

It was established through a two-tailed t-test that there was not a significant difference between the amount of *E. coli* at Sunrise Bridge and Paradise Beach. This means that between Sunrise bridge and Paradise beach there were no major sources of *E. coli* that were added to the American River. In comparison, there was a significant difference between the *E. coli* counts at Paradise Beach and Camp Pollock, meaning there was a source somewhere between Camp Pollock and Paradise Beach, although the mean *E. coli* count only went up 37.4 MPN/100 mL. There was a significant increase in *E. coli* counts between Camp Pollock and Tiscornia Beach. The *E. coli* count increased 593.5 MPN/100 mL in 2019 and 692.5 MPN/100 mL in 2020. The large increase between Camp Pollock and Tiscornia Beach lends one to conclude there must be a source of *E. coli* between Camp Pollock and Tiscornia Beach (Whitford, 2020).

With the EPA and CFWB both setting the acceptable level of 320 MPN/100 mL, the *E. coli* count found at Tiscornia Beach is the level of *E. coli* that the public needs to be concerned about and the level that Sacramento needs to make mitigation plans to reduce. Adam Laputz, an executive officer with the CFWB said 'The Water Board knows there is a problem' with the amount of *E. coli* in the American River (Reyes-Velarde, 2019). An issue that has arisen is that even though the amount of *E. coli* is significantly higher in the American River where there are many homeless camp sites, the CFWB and other regional park organizations are not ready to declare the homeless defecation is causing the *E. coli* problem in the river. Lisa Bellas, director of Sacramento County Regional Parks states that 'Until the origin of the bacteria is determined, officials can't say how they will handle the pollution' (Reyes-Velarde, 2019). It has been touted that the amount of *E. coli* in the American River between Camp Pollock and Tiscornia Park is not due to the homeless but is due to the excrement from geese and migrating birds and dogs. It is true that one can only assume that the *E. coli* is from the homeless and not from other sources. The CFWB has announced that starting in 2020-21 they will begin a 3-year DNA analysis of the *E. coli* samples to determine the potential source of the *E. coli*, whether from human or from wildlife.

<u>Possible Sources of *E. coli* in American River</u>

In any river there may be multiple sources of *E. coli* contamination. In the American River, the CVWB has stated that they do not know for a fact what the sources of the *E. coli* are. The CVWB is currently doing DNA tests to determine whether the *E. coli* is from human, mammal, and/or waterfowl. In addition, the CVWB has also stated that the *E. coli* may be from sewage overflow or leaking septic tanks. What the CVWB has not explicitly stated is that the *E.*

coli may be from the homeless camps along the Lower American River, nor have they acknowledged that large quantities of *E. coli* may be stored in the sediments in and along the river.

Source of E. coli: Sewage Overflow

The source of *E. coli* in the American River may be from sewage sanitary overflows (SSO's). The City of Sacramento Department of Utilities is responsible for providing and maintaining flood control, storm drainage, sewer collection, and drinking water services for the city. The city has 2 sewage systems. One sewage system was installed in the late 1800's and serves 40 percent of the city. Sixty percent of the city is served by a second sewer system (Wilk, 2019). The entire sewer system consists of 4,682 miles of pipeline, has 299,000 service connections, and serves 1.2 million people in the Sacramento area. (California Coastkeeper Alliance vs County of Sacramento, Sacramento Area Sewer District, Sacramento County Department of Water Resources, 2021). The collection system collects sewage from residents, agricultural, industrial, and commercial sources. The sewage collection system had over 749 SSO's between July 14, 2018, and October 14, 2021, which is approximately 250 sewage overflows every year (California Coastkeeper Alliance vs County of Sacramento, Sacramento Area Sewer District, Sacramento County Department of Water Resources, 2021). The sewage overflow typically ends up in the local Sacramento waterways with rain runoff. Currently there is a federal suit against Sacramento County, Sacramento Area Sewer District, and Sacramento County Department of Water Resources addressing the unlawful point source discharges into the local waterways (California Coastkeeper Alliance vs County of Sacramento, Sacramento Area Sewer District, Sacramento County Department of Water Resources, 2021).

Source of E. coli: Leaking Septic Tanks

The CFWB has stated that the source of some of the *E. coli* could be leaking septic tanks along the American River (Sabalow & Moleski, 2019). A small amount of *E. coli* may originate from leaky septic tanks, but the number of septic tanks along the Lower American River are few. In the Sacramento area, if sewer is available within 200 feet of the property, the homeowner is required to connect to the sewer system. (Sacramento County, 2021). The Sacramento County and City Sewer System covers the area along the Lower American River, therefore septic tanks are not needed along the Lower American River. (Figure 3)

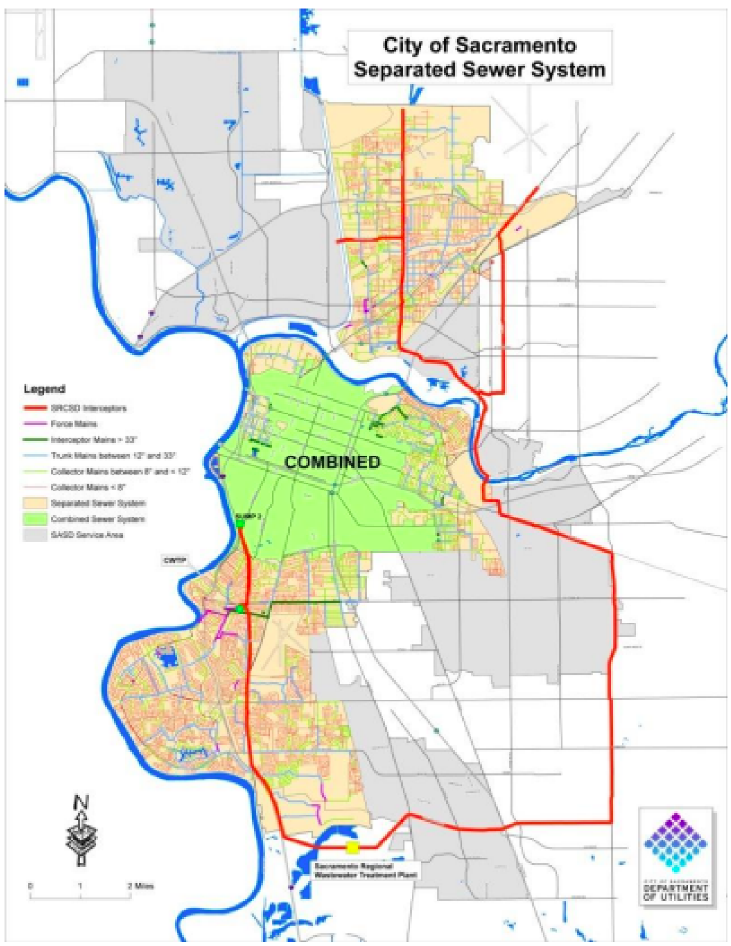

Figure 3: Sacramento Sewer System. The labeled blue lines are the American River and Sacramento River. The Sacramento sewer system surrounds the American River (City of Sacramento, 2014).

The problem with identifying leaking septic tanks as a main source of *E. coli* is if septic tanks were leaking along the American River, one would expect the numbers of *E. coli* to slowly increase along the American River with each additional leaking septic tank. Since the *E. coli* numbers along the American River are under the EPA threshold until the *E. coli* counts spike at Discovery Park and Tiscornia Beach, the *E. coli* problem at Discovery Park and Tiscornia Beach are not due to leaking septic tanks along the American River. In addition, leaking septic tanks are not the problem at Discovery Park and Tiscornia Beach because the Sacramento Sewer system is available to all residents and commercial buildings near Discovery Park and Tiscornia Beach.

Source of E. coli: Animals

Not only do humans have to excrete feces, but mammals, birds, and fish in and along the American River must also excrete feces, adding to the *E. coli* found in and around the American River. The CVWB has claimed that dogs might be a major source of *E. coli* in the American River. Dogs are a favorite companion for many people, including the homeless along the American River, but dogs have not been found to be a major source of *E. coli*. In Italy, there are a large number of dog stools present in the streets, and therefore the risk for public health due to pathogenic enteric bacteria from the dogs was studied. Four hundred and eighteen dogs were studied, and only 18% of the fecal samples from the dogs were positive for *E. coli*. In other studies, up to 37% of fecal samples from dogs were positive for *E. coli* (Cinquiepalmi, et al., 2013). According to past studies, after the DNA testing is done on the *E. coli* found in the Lower American River, dogs very well may not turn out to be the major *E. coli* source for the Lower American River.

On the other hand, migrating and non-migrating birds have been shown to be regular sources of *E. coli*. In one study of migrating and non-migrating birds in Saudi Arabia, of 27 non-migrating bird feces samples, 92% of the feces sampled contained *E. coli*. In the same study out of 18 migrating bird feces samples, 94% of the feces sampled contained *E. coli* (Shobrak & Abo-Amer, 2015). In a study done on birds in Sao Paulo, Brazil, 516 birds were studied for the presence *E. coli* in the feces, and 78% of the feces samples were positive for *E. coli*. The question remains, are there enough birds in the Discovery Park and Tiscornia Beach area to cause the significantly high counts of *E. coli* all year round.

Black tailed deer are often spotted at the American River edge. Deer feces does contain *E. coli*, but deer tend to defecate near their bedding areas and as they feed in the bushes (World Deer, 2021). The *E. coli* that is found in the deer feces near their bedding and under the bushes must then reach the river as part of water runoff. *E. coli* in deer feces dies off fastest at high and low temperatures, 35^{o}C and 4^{o}C, respectfully, as compared to medium temperatures, like 20^{o}C. In addition, the *E. coli* survival rate is highest in saturated moisture conditions as compared to dry conditions. *E. coli* survives best in runoff in warm wet weather conditions like those often found in the Midwest during the summer months (Guber, Fry, Ives, & Rose, 2015). With Sacramento being hot and dry in the summer months of June through September, the likelihood of *E. coli* surviving to possible high rain runoff periods in December through February are unlikely (Weather Spark, 2021). Sacramento also gets very cold in the winter months between December and February, again entertaining environmental conditions that do not promote *E. coli* survival and reproduction (Weather Spark, 2021). Sacramento does not have warm wet times of the year, rather Sacramento's wet time of the year is when it is the coldest. Therefore, when *E.*

coli from deer feces is part of rain runoff in the winter, the *E. coli* survival and reproduction rate is low.

In addition to the presence of *E. coli* in deer feces, it has been found in a lab situation that of 39 white tailed deer who ate plants inoculated with the pathogenic *E. coli 0157:H7, E. coli O157:H7* was isolated from only 1 deer fecal sample (Fisher, Zhao, & Doyle, 2001). With the weather conditions in Sacramento, and the low rate of the pathogenic *E. coli* found in deer, it is unlikely that deer have a significant role in shedding unhealthy volumes of *E. coli* bacteria into the American River.

Fish are not mentioned by the CVWB as *E. coli* sources, but fish deserves a mention as a possible *E. coli* source as they live in the water contaminated by *E. coli*. Most fish actually become a sink and then an additional source for *E. coli*. Fish take in *E. coli* from drinking the water and from scavenging through the water's bottom soil. The *E. coli* do not make the fish sick (Gao, 2018). The *E. coli* that fish consume have been found to reproduce in the intestines and then be excreted back out into the water ways. Fish are even considered as vectors of *E. coli* bacteria originating from warm blooded animal intestines. A group of scientists from University of Minnesota collected brown bullheads, carp, Eurasian ruffe, white perch, round gobies, and rock bass from an area in Lake Superior and found *E. coli* with genetic matches to Canadian geese, mallard ducks, and humans in the intestines of the fish (Thomas, 2008). The fish become sources of *E. coli* because they excrete the *E. coli* from birds and humans that they took in, right back out into the environment by way of their feces.

Source of E. coli: Homeless Excrement

As most people use their own personal bathroom to defecate or find a public toilet when they are, to defecate, there is a growing homeless population that do not have access to toilets on an everyday basis. In California the displaced population rates are increasing. In 2020, according to the U.S. Department of Housing and Urban Development, 161,548 individuals are identified as homeless in California, a 7% increase since 2019 (U.S. Department of Housing and Urban Development, 2021). Many of the homeless choose to live by rivers where they can wash and, unfortunately, excrete feces and urine into the river. Raw sewage in the rivers is becoming a problem in California waters. According to the Sacramento County 'Point in Time Homeless Count', there were approximately 5570 homeless at the end of 2019 (CSUSacramento, 2019). The homeless count is predicted to be at least double the 5570 at the end of 2021 (Howland, 2021). Seventy percent of the homeless do not have regular beds and many of those choose to establish their homes along the American River (CSUSacramento, 2019)(Figure 4).

Figure 4: Homeless Camp. Homeless camp along the lower American River (Save the American River Association, 2017).

Homeless who live by a river do not have daily access to bathrooms and showers. The river is their place to wash their bodies, urinate, and defecate. There have been few studies directly correlating homeless to *E. coli* pollution in rivers, probably due to the sensitive societal issues that the studies would tread on. San Diego State University did do a small-scale study on the amounts of *E. coli* upstream and downstream of three homeless encampments along the San Diego River watershed. Four to eight water samples were collected upstream and downstream of three different homeless encampments. They collected the samples at 2 of the encampments between June and November 2018, and at one of the encampments between June and August 2019. They compared $\log_{10}$ transformed *E. coli* concentration data. There was significantly more *E. coli* downstream of the homeless camps than upstream of the homeless camps. In summary, this study showed that the San Diego River does contain increased human related pollutants such as *E. coli* downstream of the homeless camps (Verbyla, et al., 2021). In Sacramento, a major concentration of the homeless camps are found along the American River Parkway between Camp Pollock and Tiscornia Bay (Figure 5). As shown on the map below, the majority of the homeless camps along the American River start just before Camp Pollock (Site #2) and continue along the river almost to Tiscornia Beach (Site #1).

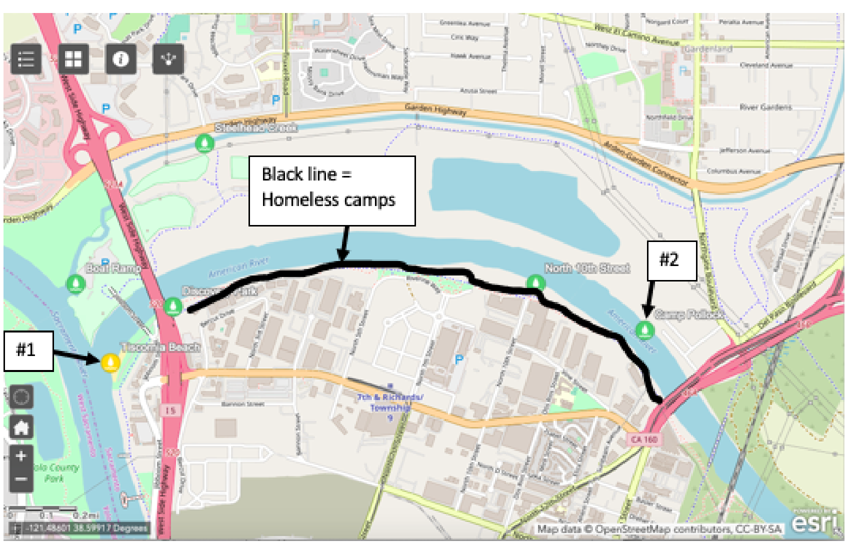

Figure 5: Homeless Camp Map. The map is an enlarged section of the lowest part of the American River. Camp Pollock is at site #2 and is the beginning of the 2.25 km section of highly concentrated homeless camps. Tiscornia Beach is site #1 and is immediately downstream of the most highly concentrated homeless camps. The dark black line is where the majority of the homeless camp are found along the American River. (Whitford, 2020).

At Tiscornia Beach (Site #1) there were 13 weeks in 2019 where the *E. coli* counts were above 1000 MPN/100mL., and in 2021, there were 16 weeks where the *E. coli* counts were above 1000 MPN/100mL. Whereas, at Camp Pollock (Site #2) in both 2019 and 2021, the *E. coli* counts were never over 1000 MPN/100mL (Central Valley Water District, 2021). Unless an alternative cause of the large increase in *E. coli* counts between Camp Pollock and Tiscornia Beach can be identified, one can conclude that the number of homeless camps along the American River has resulted in the high levels of *E. coli* between Camp Pollock and Tiscornia Beach.

Source of E. coli: Sediment

Sacramento has considered *E. coli* as being from biotic sources but have not considered the abiotic sources such as sediment in and along the river. Sediment has been found to be a storage sink, a place for reproduction, and a consistent emitter of *E. coli* in many river ecosystems. *E. coli* counts can even be higher in the sediments than in the water (Whitman & Nevers, 2003). *E. coli* populations in the sand and sediment are successful because the *E. coli* are shielded from photo decay and the sediment has nurturing conditions for the *E. coli* to survive and reproduce (Fluke, Gonzalez-Pinzon, & Thomson, 2019).

In Albuquerque, New Mexico, they studied the *E. coli* load in the river water and in the sediments along a 60 km. stretch of the Rio Grande. They found that sites upstream of the city had low *E. coli* counts in both the water and sediments. In comparison, downstream of the city, all the test sites had high *E. coli* loads in the water and sediments. What was interesting was that the differences in the data between water *E. coli* counts and sediment *E. coli* counts. It was determined the fine sediment in the Rio Grande riverbed was a source of *E. coli* and frequently contributed to above healthy *E. coli* counts in the river. In Albuquerque they are currently researching ways to mitigate the sediment *E. coli*, as well as point sources for *E. coli* (Fluke, Gonzalez-Pinzon, & Thomson, 2019).

In another study, done in Hamilton Harbour at the west end of Lake Ontario, Canada, the sand was ultimately determined to be the source of the *E. coli* polluted water. At one point in Hamilton Harbour, 95% of the beaches were not accessible to the public because of *E. coli* levels above standard of 100 MPN/100 mL (Milne, Gilpin, & Fortuna, 2017). The city implemented a strict remediation and mitigation program to reduce the sewage overflow into the waterways. They reduced the *E. coli* numbers to below the 100 MPN/100 mL at all but two beaches. The city then determined that the *E. coli* at the two beaches was due to fecal material from geese, ducks, and gulls. The city installed bird deterrent fences, vegetations barriers, and buoys paralleling the beach to prevent birds from accessing the beach. They also mechanically groomed the sand along the beaches. The *E. coli* numbers did decrease to under 100 MPN/100 mL most of the time, but there were still times the beach had to be closed due to high *E. coli* counts. They have since determined that the sand is a long-term storage for the E. *coli*, and depending on the tide, directly impacts the *E. coli* levels in the water (Milne, Gilpin, & Fortuna, 2017). What Sacramento needs to be aware of is if the *E. coli* is from human waste, dog waste, or bird waste, the sediment may be a reservoir for *E. coli* that will also have to be addressed in the mitigation plan.

***E. coli* Mitigation Methods**

As people deserve clean water, free of pathogens and pollutants found in human or animal waste moving into the river, the best way to maintain and ensure a clean American River waterway is to completely stop fecal material from entering the water. To completely stop fecal material from moving into the river in an urban area like Sacramento is impossible, so mitigation of the high counts of *E. coli* in a river area is also necessary to reduce *E. coli* in the water and the surrounding parkway.

Mitigation of the Lower American River *E. coli* problem could be divided into 3 general methods. One method would be to reduce the direct sources of *E. coli* by improving the stormwater filtering system or increasing access to riverfront bathrooms. The second method of mitigation would be to add filtering systems on the edge of the river, like wetlands, canals, riparian habitats, and reservoirs to capture, remediate, and clean the water before the water enters the river again from the original sources. The third method of mitigation would be to clean the water and sediment that currently has high levels of *E. coli*.

Mitigation Method: Stormwater Projects

A recommendation for Sacramento to reduce sewage spill runoff is to design and implement a stormwater recovery filter system. Sacramento already has a model stormwater management project in their backyard, as Sacramento State has built 24 low-impact development (LID) devices to filter stormwater runoff from the campus before the water reaches the American River. The filter system is found at seven campus locations and filters 2.9 million gallons of rainwater every year. The devices are hidden in small gardens of drought tolerant plants, with porous walkways made of crunch concrete. Before the project, sediment and pollutants were pumped over the levee directly into the American River. The LID devices have reduced the sediments and pollutants flowing into the river by 60 to 90 percent (Sac State Magazine, 2017).

Another model that could be used to reduce the stormwater flow into the American River is a system used in Kalkallo, Australia called a Green Stormwater Infrastructure (GSI). The system channels stormwater to where the water will be naturally filtered in a wetland. The water could be channeled using current drains and altered pipes, or by bioswales that run along natural flooding areas. Bioswale are vegetated, shallow, landscaped depressions or canals designed to capture, treat, and infiltrate stormwater. At the wetland area native perennial grasses and drought tolerant plants could be planted for easy maintenance. In addition, wetlands could be built along the levees or along the creeks and rivers to move stormwater and flood water away from urban areas to the filtering wetlands, to filter the water before entering the American and Sacramento Rivers (Wilk, 2019).

In Oregon, the Willamette River was unswimmable for 40 years. Portland government took the situation seriously and budgeted 1.4 billion dollars to improve the water quality with a program called the 'Big Pipe Project'. The Big Pipe Project took 20 years to develop and build but has dropped the sewage overflow into the river by 94-99%. Before the Big Pipe Project, there were on average 50 SSO's every year. Currently, on average there are only 4 SSO's per year. The project included diverting stormwater runoff from the sewer system by adding 3000 stormwater sumps to collect street stormwater runoff and move the water toward regions that would allow water to move through in-ground filters, adding a sewer separation area where the storm sewer water is directed toward a 26 acre constructed wetland area to let the overflow water slowly seep into filtered ground at the wetland, and diverting clean stream water to go directly into the Willamette, and not into the sewer system, They also added 3 big pipes, as big as 6 miles long and 22 feet in diameter, moving millions of gallons of sewage to treatment plants (Portland Government, 2021).

There are many options to improve on Sacramento's sewage system, Sacramento needs to make a plan, and like Portland, a 20-year plan is a better plan than no plan.

Mitigation Method: Bathrooms for Homeless

Access to safe, clean water, and sanitation is essential for the safety of all those around. For most people public toilets are an expected necessity wherever one lands. If you are traveling in France, Germany, Japan, or United States public bathrooms are there when you need them. If one travels from one country to another, one expects public bathrooms to be present as a normal part of public health. But, when it comes to the homeless, public bathrooms have become a nuisance for cities and local governments to supply. One of the main assumed sources for *E. coli* in the Lower American River are the homeless camps. Sacramento has attempted to supply the homeless with portable toilets to alleviate the raw sewage in and along the American River Parkway. The city officials have since eliminated the portable toilets because the homeless lived in the bathrooms, clogged up the toilets with sleeping bags, tipped over the toilets, and set the toilets on fire. (Sabalow & Moleski, 2019). Sacramento does have permanent public bathrooms near the homeless sites, but the park rangers lock the permanent bathrooms at night because the homeless do drugs in them or use the bathrooms for prostitution (Sabalow & Moleski, 2019).

There is still hope for a bathroom option for the homeless in Sacramento. In San Francisco, the city had such a problem with homeless urinating and defecating in the street, they decided that the cost of supporting the homeless with restrooms was worth the value of cleaner streets. San Francisco government has supplied the city with 55 public toilets in the 'Pit Stop' program (Howey, 2020). These toilets are either permanent fixtures or are portables with two toilets that can be trucked in and out. The 'Pit Stops' have receptacles for dog waste and syringes

(Har, 2019). The ‘Pit Stops’ have attendants assigned to the restroom station, and they ‘check the bathrooms after every use and knock on the doors to make sure the users are not doing drugs or illicit activity’ (Har, 2019). San Francisco says that staffing has made the difference as the staff breaks up fights, prevent overdoses, and greets regulars. The staff are often men that have left prison and want to help those in poverty, with addiction, and with mental illness. (Har, 2019).

The ‘Pit Stop’ program has now expanded to Los Angeles. Los Angeles currently has 19 mobile pit stop toilets. (Figure 6). Again, all the ‘Pit Stops’ are staffed with practitioners. The practitioners are all hired and trained by the nonprofit company, Urban Alchemy. The practitioners are trained on de-escalation, sexual harassment, managing stress, and workforce development skills. “Jay Flott started as a practitioner or the overnight shift on Skid Row in April. He said he initially did it because he needed work but has since established relationships with the people in the area.” (Ward, 2021).

Figure 6 : Pit Stop Toilet: Sample Pit Stop Toilet in Los Angeles (Ward, 2021).

Sacramento could learn from San Francisco and Los Angeles' positive experiences with managing the excrement situation in the cities and use a similar model including the experience of Urban Alchemy. Sacramento would not have to have 55 toilets all around the city. Sacramento could put their money toward building one or two large permanent restroom facilities near the Discovery Park and Tiscornia Beach. The permanent restroom facilities could each be staffed by a few practitioners. The restroom facility could have two sides with multiple restrooms in each side, so that if one side needs to be closed to clean or fix, the other side could be opened for use. The facility could be designed so that it could be cleaned with hoses with a drain at a low point in the floor. The facility could be designed so that it pleasant to look at with a natural style since it would be near the American River Parkway, not just a cement block house like so many bathrooms. The cost would be a lot less than San Francisco, since there would be a cost for the building, but the cost would be less for regular attendants since San Francisco has 55 stations and Sacramento would only need two or three.

There will always be homeless near the American River, so build them the bathrooms. The annual cost for San Francisco toilets is $244,000- $373,000 depending on the type of unit. (Ward, 2021). The estimate does not include supplies, materials, or replacement costs. The cost for Los Angeles' 19 'Pit Stop' toilets is $7 million, making it about $368,000 per toilet (Ward, 2021) The cost of the toilets is a lot, but the cost of losing tourism and conventions due to the 'filthy' and 'disgusting' evaluations of the city was costing San Francisco millions of dollars. (Ward, 2021).

Alexandria Boehm, a Stanford professor who studies water quality and contamination at public beaches said "she wouldn't swim or let a child get in the water at Tiscornia Beach after reviewing the state's *E. coli* sampling data and learning that homeless camps were upstream.

You don't need a Ph.D. to say, there's somebody pooping in the river. Let's put a bathroom out there." (Sabalow & Moleski, 2019).

Mitigation Method: Constructed Wetlands

Even with bathrooms built along the Lower American River, mitigation methods to reduce the *E. coli* from human, dog, and wildlife excrement that ends up in water in runoff is an important addition to a restoration plan. Creating wetlands or reservoirs along the American River waterway may be a possible mitigation effort to reduce the *E. coli* in the river. In Alberta, Canada they did a study showing 75% of specific sections of the river that had lower *E. coli* counts downstream as compared to upstream, had irrigation canals, streams, or reservoirs between the upstream *E. coli* source and downstream part of the river. All the canals, stream and reservoirs had low velocities and high residency times (Gannon, et al., 2005). In the downstream sections of the river where lower *E. coli* counts were found as compared to the upstream sections of the river, approximately 90% of the *E. coli* was removed. The shallow water allowed the *E. coli* to be exposed to UV light, and the *E. coli* died off rapidly (Gannon, et al., 2005). To reproduce this method in the American River, shallow canals or shallow reservoirs of water could be created along the shore near the homeless camps or just below the homeless camps to slow the water down and allow the *E. coli* time to be exposed to higher temperatures and UV light or settle into the sediments. The water exiting the slow water reservoir region would contain reduced *E. coli* counts as compared to the water entering the reservoir area.

In conjunction with the slow water and reservoir area, constructed wetland areas would improve the water entering the river. It has been found that wetlands provide an ecosystem service and can improve water quality from unsafe parameters to safe parameters. (Rea, Bisesi, Misch, Andridge, & Lee, 2015). If wetlands are present near drinking water or recreational areas, the pollution in the water can be significantly reduced. (Rea, Bisesi, Misch, Andridge, & Lee, 2015).

An additional method to improve water quality in waterways is to construct fences. The fences could be used to maintain a riparian area between the human intrusion and the river. In New Zealand they found adding fences to create a buffer zone between human or agriculture use, and the river reduced the *E. coli* levels in the river. The buffer zone acted as an ecosystem service to help keep the waterways cleaner as well as reduced erosion. The buffer zones were no wider than five meters and were restored to be a riparian ecosystem, rather than hard pan dirt. New Zealand recruited farmers to help and established a group called 'Dairying and Clean Streams Accord' to promote sustainable riparian management for their cows. They also recruited school children be establishing programs where school children were brought to the waterways to plant plants and monitor the growth of the riparian vegetation. (McKergow, Matheson, & Quinn, 2016)..

Currently the city of Mankato, Minnesota is working on a project to construct lake sized holding ponds and restore wetlands to alleviate flooding and improve water quality. Their project is focusing on natural water quality improvement versus spending money on more sewage treatment plants. Implementing, canals, reservoirs, wetlands, or fenced riparian water areas are all possible mitigation options for the Sacramento area to reduce *E. coli* in the main river. Sacramento could also recruit local community groups and school children to help create and maintain the riparian vegetation. All of these, or a combination of these restoration methods could be part of a long-term plan to reduce *E. coli* in the American River, understanding that eliminating the homeless may not be an option for many years to come and creating a clean water way should be addressed as soon as possible.

Mitigation Method: Inclines in the River

As stated earlier, the *E. coli* levels in and around Discovery Park and Tiscornia Beach are anywhere from seven to ten times greater that the acceptable health standard. Killing the *E. coli* in the water is one option to start mitigating the river water. It has been shown that UV light kills *E. coli* (Kodoth & Jones, 2015). Sacramento could use the natural sunny days to mitigate the high *E. coli* counts in the American River. Sacramento receives on average 265 sunny days per year, which means there is 265 days where the American river is exposed to natural UV light (Current Results Weather and Science Facts, 2021). Currently, much of the *E. coli* is protected from the UV light by being down deep in the river. By generating a thin film of water and exposing the thin film of water to UV light, pathogens are inactivated (Figure 7). The inactivation rate of pathogens increases by 63% when exposed to UV light as compared to no UV light (Hawley & Fallowfield, 2018).

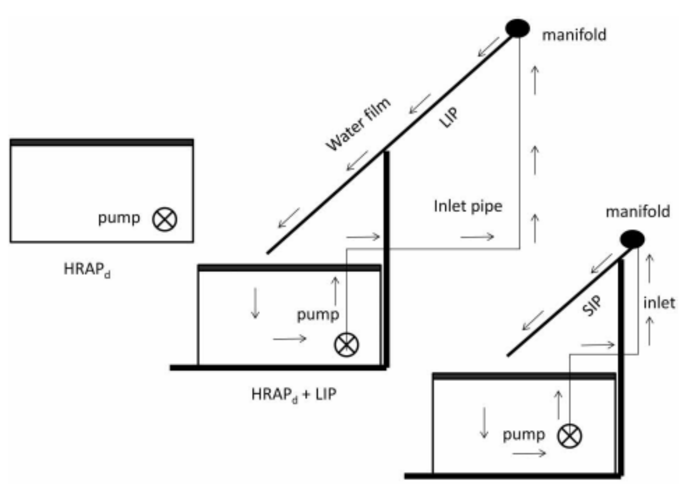

Figure 7: Experimental Water Incline System. This incline system exposing thin layers of water to UV light. The UV light kills pathogens (Hawley & Fallowfield, 2018).

If a pump brought water up from the depths of the American River to the surface and over the exposed inclines in the river, a bottom-up circulation would be established whereby *E. coli* would be exposed to Sacramento's sunny days, and thus exposed to natural UV light. With a continuous flow of water over the inclines, *E. coli* would continuously be killed. The bottom-up flow might even reduce *E. coli* more as the bacteria from the bottom of the river are continually moved to the water's surface, exposing the *E. coli* to natural sunlight and UV light at the water's surface.

The use of inclines to reduce pathogens in waterways is currently an in lab theoretical solution to mitigate increased levels of *E. coli* in a body of water. Maybe the idea could be experimentally designed and implemented by local Sacramento State professors and students.

Mitigation Method: Clean Sand and Sediment

Mitigating *E. coli* laced sediment is probably the most difficult task Sacramento will need to address. Most mitigation methods and plans to clean up waterways are methods to reduce the sources of the pollutants entering the waterway. Although, reducing the sources of *E. coli* may not completely fix the problem, as exemplified in the Hamilton Harbour beach situation. At Hamilton Harbour they eliminated the human and bird sources of *E. coli*, but still had time periods where the *E. coli* counts in the water rose above healthy standards. The *E. coli* was found to be in the sand. To address the *E. coli* in the sand at Hamilton Harbour, three sand grooming techniques were applied. First routine grooming with a thatched rake, second deep grooming with a modified rake, and third no grooming. The results showed there was no significant reduction of *E. coli* in either raking or not raking the sand on the beaches. The Hamilton Harbour Beach Management next tried adding clean sand and replacing sand with clean sand. Within two weeks, *E. coli* recolonized in all the new sand. As stated before, reducing *E. coli* in the sediment may be a difficult task.

Dredging sand, cleaning the sand, and replacing the sand is another possible option. On a small scale, leatherback sea turtle researchers in Costa Rica practice the dredge, clean, and return method. The researchers in Costa Rica dig artificial nests for leatherback sea turtles on the beaches where the leatherback sea turtle's lay eggs. The researchers transfer the eggs from the real nests dug by the mother turtles to the artificial nests dug by the researchers. The artificial nests are used for studying the reproduction rates of leatherback sea turtles and to protect the hatchlings from poachers and predators. Each year the scientists identify an area where the artificial leatherback sea turtle nests will be, they dig up triple the depth of the nests, they clean the sand with bleach, and then they replace the sand, clean and ready for the current year's leatherback sea turtle eggs and babies. Even cleaned with bleach, approximately 15% of the babies die due to pathogens in the sand. Unfortunately, in nature, up to 80% of the baby turtles die due to pathogens in the sand, so cleaning the sand and replacing the sand is a successful method to reduce the pathogens in the sand and reduce leatherback sea turtle death in the sand nests (Claudio, 2021).

Dredging river sediment, although would help improve the sediment and river water quality in the long run, would result in potential short-term increase of pollution due to resuspension of the *E. coli* (Abia, Jame, Ubomba-Jaswa, & Momba, 2017). Since dredging sediment would cause spikes in *E. coli* counts, dredging sediment as a mitigation method would have to come after other mitigation methods were in place, Dredging would also negatively impact the micro invertebrate and macroinvertebrate populations resulting in a bottom-up disruption of the ecosystem. in the river. Not only would less invertebrates decrease the fish population due to less food, dredging reduces habitats for fish refuge from currents, injures and disoriented fish fry, and increases water turbidity resulting in decreased disease resistance suffocation (Haider, 2016). In the end, even though the sediments in the American River are a source of *E. coli*, plans to mitigate the *E. coli* permeated sediments in the American River would need more research to determine the cost effectiveness of the process.

Conclusion

In summary, the Lower American River is highly contaminated with *E. coli*, a common enteric bacterium with possible pathogenic forms, such as *E. coli 0157:H7*. Sacramento's Lower American River has recorded higher than allowable *E. coli* counts for healthy recreational use for over 10 years now. The most significant source of the *E. coli* found in the Lower American is from the direct human excrement from the homeless population living along the American River where the highest *E. coli* counts have been found for the past three years. Additional significant *E. coli* sources that add to the high *E. coli* count in the American River is the *E. coli* found in the river sediment and the urban sewage runoff. The most negligible *E. coli* sources adding to the American River *E. coli* counts would be from the dog, bird, and wild animal feces and septic tanks.

The Central Valley Bacteria Source Identification Screening Study was done 10 years ago which showed that six out of twelve waterways in the Sacramento area, including the American River, had unsafe levels of *E. coli* (University California Davis, 2011). The report summarizes the quantitative water quality values without giving any recommendations for future mitigation programs. It is now 10 years later, with an additional three-year study done where weekly *E. coli* counts at 10 places in the Lower American River were taken, resulting in more evidence that *E. coli* levels are chronically well above safe EPA standards. Now, an additional 3-year study is in progress to analyze the DNA of the *E. coli* found in the American River to potentially find the sources of the *E. coli*. The fact that the *E. coli* levels were identified as being unsafe ten years ago, and the CVWB has spent money to prove the *E. coli* levels are above safe EPA standards, seems like a waste of government time and money. The *E. coli* problem has been identified over and over, and now it is time to act to research and make mitigation plans to reduce the unsafe levels of *E. coli* in the American River and Sacramento area waterways.

Sacramento's problems are not going away by postponing action for the sake of doing new studies. Maybe the money to do the new studies should be spent to start a collaborative effort by the government, local industries, local organizations, and individuals to start remediating the polluted Lower American River. The remediation of the water can be successful with the efforts of the whole community. Researching potential mitigation plans and making a long-term plan for the American River, will in the end be the best plan, not doing more studies to identify a problem that is currently known to be a problem.

Other communities around the world have made it a priority to clean up their rivers so that their polluted rivers become swimming hotspots. In United States, communities have received grants and partnered with federal, state, local, community, and advocacy organizations, including local Universities to clean up their rivers. Mystic River in the Boston area went from an EPA Water Quality Report Card grade of an F in 2003 to a B in 2019 (EPA, 2020). In Puerto Rico, the Cano Martin Pena Channel, a channel connecting the San Jose Lagoon and San Juan Bay, has been a restoration project since 1992. The 20-year restoration project brought the community together, not only addressing sewage pollution issues but also social and environmental justice issues. The restoration project included channel dredging, wastewater and drinking water infrastructure, relocation of families, and improving socio-economic conditions resulting in a success for the whole Puerto Rican community (EPA, 2021). Copenhagen, Norway has restored their heavily polluted and industrial port into a clean, thriving, swimmable aquatic environment. It took 500 million Euros and a 20-year long term plan that the whole community adhered to, with the results of more recreation, more nature than they have seen in decades, and more tourism (The Danish Mistry of the Environment, 2020). The Seine River running through Paris has not allowed swimming for the past century due to high *E. coli* loads. In 2018 they initiated a 1 billion Euro project to reduce the *E. coli* sources and clean up the river so the open water and triathlon swimming events at the 2024 Olympics can be held in the river (Mouchel, et al., 2020).

The City of Sacramento and the CVWB need to follow the lead of many other global communities and make a long-term mitigation plan to reduce the *E. coli* in the local waterways. As other regions of the world implement multiple methods to reduce *E. coli*, Sacramento must also recognize that a single method, such as reducing sewage overflow, adding bathrooms, or creating service ecosystems alone may not be effective. Therefore, hybrid techniques, combining two or more methods, are more widely recommended for effective treatment of the waterway (Anawar & Chowdhury, 2020). In the end, the goal of the Sacramento American River mitigation plan should be one where on Memorial Day weekend, when people pack the beaches of Discovery Park and Tiscornia Beach along the American River, the *E. coli* levels are not at the dangerously high 2400 MPN/100 mL, but at the safe 100 MPN/100 mL or less, for a day of healthy fun.

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