CPS 2018 RFP
FINAL PROJECT REPORT

Project Title

Development of a model to predict the impact of sediments on microbial irrigation water quality

Project Period

January 1, 2019 – December 31, 2020 (extended to March 31, 2021)

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Objectives

1. *Identify factors which would result in the re-suspension of sediment-bound bacteria/viruses in irrigation channels (i.e., rainfall events, wind), specifically E. coli, L. monocytogenes, MS2 virus and phiX174 virus (also used as a surrogate for enteric viral pathogens).*
2. *Quantify the impact of resuspension of different levels of these bacteria and viruses on the quality of the overlaying water.*
3. *Suggest guidelines for growers/producers to minimize the occurrence of pathogenic bacteria and viruses in the irrigation water.*

Funding for this project provided by the Center for Produce Safety through:
CDFA SCBGP grant# 18-0001-079-SC

FINAL REPORT

Abstract

Sediments in irrigation canals can act a reservoir for both pathogenic viruses and bacteria. These organisms are known to occur in greater concentrations in the sediments than in the overlaying water and survive for longer periods of time. The overall goal of this study was to determine the impact sediment properties and flow conditions on the resuspension of viruses and bacteria and assess the relative occurrence of *Escherichia coli* and *Listeria monocytogenes* in sediments and overlaying waters in irrigation canals in Arizona. The study had three phases: 1) determine the impact of sediment type (sand, sandy, loam) and microorganism type (*E. coli*, *L. monocytogenes,* MS2 and phiX174 [used as models for human pathogenic viruses]) and flow conditions on their resuspension in laboratory experiments with a laboratory hydraulic flume; 2) determine the occurrence of *E. coli* and *L. monocytogenes* in irrigation canals in Arizona; and 3) apply machine learning to determine the impact of *E. coli* in the sediments on the microbial quality of the overlaying water. Results indicate that the virus phiX174 was resuspended to a greater degree than MS2 and this may be associated with a lower degree of adsorption to the sediment than the more hydrophobic MS2. Both flow and sediment type played a role in resuspension. Bacteria resuspension from sandy sediments occurred more easily than from sandy loam or loam sediments. Using machine learning it was found that incorporating sediment features improved the ability to predict the level of *E. coli* in the water. The concentration of *E. coli* in sediment and bed shear stress were major factors influencing *E. coli* concentration in irrigation water. These findings demonstrate the role of *E. coli* in the sediment in influencing the levels of *E. coli* in irrigation water. In addition, elevated water temperatures and turbidity of the irrigation water were related to the level of *E. coli* in the irrigation water in the canals. These relationships can be applied to water quality models to simulate *E. coli* and *L. monocytogenes* transport in water and sediments and can be used as a predictive tool for management of irrigation water quality. *L. monocytogenes* was not detected in the sediments or water of irrigation canals in Arizona, and these do not appear to be a source of *L. monocytogenes* in this region.

Background

Multiple studies have reported high levels of pathogens in sediment, ranging from 10 to 10,000 times greater than the concentrations in the overlaying water (Bai and Lung 2005; Davies et al. 1995). Although water in an irrigation canal may be free of microbial pathogens, changes in flow velocity or other environmental factors may result in their resuspension from the bed sediment (Pachepsky et al. 2011; Zhou et al. 2017). When crop irrigation is initiated, flowing water can entrain sediment and pathogens and consequently impair water quality. Nevertheless, there is limited quantitative information on the factors controlling the resuspension of pathogens from bed sediment (Ashbolt et al. 2010).

Events which cause resuspension of sediments can include rainfall, storm water runoff, and flow rate changes. An outbreak of *E. coli* O145 associated with romaine lettuce harvested from the Yuma area was attributed to a period proceeding a period of heavy rainfall (Taylor et al. 2010). In addition to *E. coli*, norovirus is the most common cause of foodborne illness in the United States. Viruses can also accumulate to greater concentrations in sediments and are a potential risk when resuspended (Gerba and McLeod 1976).

Among the limited number of studies regarding viral pathogen resuspension and transport in the sediment-water environment (Hassard et al. 2016), the majority use *Escherichia coli* as an indicator pathogen (de Brauwere et al. 2014). Some studies have correlated *E. coli* resuspension and deposition rate with flow properties (e.g., discharge, velocity) through a power-law function, and defined threshold velocities for its resuspension and settlement (Collins and Rutherford 2004; Tian et al. 2002; Wu et al. 2009). Others have defined a critical shear stress for *E. coli* resuspension by correlating bacterial concentration in the bed sediment and bed shear stress (Bai and Lung 2005; Jamieson et al. 2005; Sanders et al. 2005). However, *E. coli* does not reflect virus behavior in aquatic systems (Jurzik et al. 2010). Viruses are far smaller than bacteria and can survive longer in the environment. Pathogenic human viruses spread via the fecal-oral route can remain viable in the water column for more than 2 months (Lopman et al. 2012). Because of the difficulties involved in pathogenic human virus cultivation, surrogates (e.g., phiX174, MS2 bacteriophages) are often used for environmental studies (Gerba and Kayed 2003). Zhou et al. (2017) conducted several sets of experiments comparing MS2 and *E. coli* resuspension from sediment in irrigation canals. They found the concentrations of both microorganisms correlate to bed shear stress after being resuspended in the water. They proposed empirical equations relating *E. coli* and MS2 concentration in water to the bed shear stress for sandy loam and sand sediments.

The surface properties involved with the attachment and release of microorganisms to surfaces can vary with the type of organism because of differences in surface properties, such as surface charge and hydrophobicity (Shields and Farrah 2002). The same is also true with properties of sediment type, i.e., sand, sandy loam, and loam. To better understand these influences on resuspension of these organisms, this study aimed to assess these differences using two viruses with known differences in hydrophobicity (MS2 and phiX174) and two bacteria (*E. coli* and *Listeria monocytogenes*) to sediments of different composition in laboratory studies using a hydraulic flume. In addition, field studies were conducted on the occurrence of *E. coli* and *L. monocytogenes* in irrigation canals and assessing the impact of sediment on the occurrence of these bacteria in the water column.

Research Methods

Laboratory flume experiments - methods

Flume description

Experiments were conducted in a rectangular flume, 30 cm high, 15.2 cm wide, 160.7 cm long, with a bottom slope of 0.001 (**Figure 1**). Water was pumped from a tank underneath the flume and then returned to the tank at the end via a pipe. A porous filter screen was placed at the flume entrance to increase turbulence mixing and reduce the entrance length. At the beginning of each experimental run, 184 L of water were added to the tank. After the tank was filled, the water temperature was measured and it remained nearly at a constant of 21°C. The flow rate was controlled by a valve at the flume entrance. The valve opening was correlated with flow rate prior to the experiments using a rectangular sharp-crested weir installed at the end of the flume. A tailgate at the flume end was adjusted to control water depth so that different velocities were reached at a given flow rate. Flow measurements were taken when a quasi-steady quasi-uniform flow was reached. The criterion for quasi-steady quasi-uniform flow was that flow depths at the front, middle, and end of the reach were similar, within less than 1 mm of deviation.

Sediment specifications

The three types of sediment used were classified as loam, sandy loam, and sand according to the USDA textural soil classification system (USDA 1987). According to USDA soil classification, sediment particles smaller than 0.002 mm, between 0.002 and 0.05 mm, between 0.05 and 2 mm, and between 2 and 64 mm are classified as clay, silt, sand, and gravel, respectively. Based on this, we calculated the percentage of clay, silt, sand, and gravel in each type of sediment (**Table 1**). In this study, clay and silt were considered in one group as a fine material, along with sand and gravel as two other groups. We found the sandy loam used in the study was the only sediment having all three components: 26% clay and silt, 60% sand, and 14% gravel. Loam had two components: 54% clay and silt, and 46% sand. The sand sediment had only sand-sized particles free of clay, silt, and gravel.

Microorganisms

The bacteriophages phiX174 (ATCC# 13706) and MS2 (ATTC# 155997-B), and *E. coli* (ATCC #13706) and *L. monocytogenes* (ATCC# 19114) were used in this study. Details of the methods for growth and assay of the organisms can be found in Zhou et al. (2017) and Tousi et al. (2021a).

Field studies - methods

Field data sampling sites were irrigation canals in the arid region of Arizona. A total of 152 samples—76 water and 76 corresponding sediment samples—were collected from the canals. A total of 13 features, namely physical (i.e., flow velocity, flow depth, medium size of sediment, nondimensional bed shear stress, water temperature, turbidity), meteorological (i.e., air temperature, relative humidity), chemical (i.e., pH, salinity, conductivity, total dissolved solid), and biological (i.e., *E. coli* concentration in the sediment) properties, were measured. Water samples were collected using one-liter sterile bottles. Sediment samples were collected from the channel bottom (approximately 5–10 cm into the bed surface) using Helley-Smith bed load samplers and then stored in sterile plastic zip-lock bags; each sediment sample was 500-1500 grams. Both water and sediment samples were placed immediately in a cooler filled with ice cubes. To prevent cross-contamination, after taking each sample, the sampler was dipped into the deionized (DI) water with 10% bleach for a few minutes, then rinsed outside of the canal. Afterwards, the sampler was dipped into DI water containing 10% sodium thiosulfate and rinsed again outside of the canal. These two steps were repeated at each sampling site to ensure data quality. Water pH, temperature, conductivity, salinity, and total dissolved solids were measured in situ by Oakton PCTSTestr5 (Cole-Parmer, Vernon Hills, IL; https://www.coleparmer.com). Air temperature and relative humidity were measured in situ by VWR Traceable™ Hygrometer/ Thermometer (Cole-Parmer). Turbidity was determined using a pre-calibrated Hach 2100AN turbidimeter (HACH, Loveland, CO; https://www.hach.com/). Flow velocity was measured using Marsh McBirney flow meter (HACH).

Sediment samples of 20–30 g were added to sterile buffered peptone water and mixed well by placement on a shake table for 30 min to elute bacteria. The sediment was allowed to briefly settle, and the supernatant was pipetted off and diluted, if necessary, before assay.

E. coli was quantified in water samples using the IDEXX Colilert test system (IDEXX 2013) with Quanti-tray/2000 (IDEXX Inc., Portland, ME; https://www.idexx.com/). Sample volumes of 100 ml were combined with substrate and incubated for 24 hours at 35°C. This method determines the concentration of *E. coli* by most probable number (MPN). Wells were checked for the development of yellow color indicating the presence of coliforms. Yellow color combined with fluorescence was specific for *E. coli*. Calculation of MPN/100 ml was determined by consulting the MPN tables provided with the Colilert system.

To quantify the *Listeria*, an MPN procedure was performed by dilution in 1 ml, 10 ml, 100 ml and 1 liter of normal-strength buffered Listeria enrichment broth with supplements. Samples were then incubated for 48 hours at 30°C, and 10 µl of the broth was then streaked onto Listeria Selective Agar with supplements and incubated for 48 hours at 35°C. Black colonies were selected (indicating *Listeria*) and frozen for subsequent PCR detection of *L. monocytogenes* by procedures described by Monnier et al. (2011).

The percent total dry solids were determined on duplicate samples of 20-30 g for each sediment sample following protocol (Walter, 1961). Quantification of *E. coli* used the same method as for water, with the exception that the samples were diluted due to very high numbers of *E. coli* in the canal sediments. Accordingly, both 50 ml and 0.5 ml volumes of the supernatant were analyzed using the IDEXX Colilert MPN system. In addition, a positive control was created by adding *E. coli* (ATCC# 25922) to the darkest sediment sample to confirm that trays could be correctly read for both color and fluorescence. These Quanti-trays were also inverted during the incubation so that any settled sediment remaining in the supernatant did not interfere the results visualization.

Field data analysis

Water samples were classified based on two standards. One is the irrigation water standard in Australia and New Zealand, specifically for commercial crops, that requires less than one *E. coli* CFU in 100 ml of water, named as WE. coli_L1, and the other is US EPA standard for surface water that requires less than 126 *E. coli* CFU in 100 ml of water, named as WE. coli_L126. Although US EPA requires the geometric mean of five samples to be less than 126 *E. coli* CFU per 100 ml for recreational waters, in this study, WE. coli_L126 was considered as a threshold for a single sample, a conservative approach previously taken in other studies (Eleria and Vogel 2005; Motamarri and Boccelli 2012).

For each water sample, whenever *E. coli* concentration in the water exceeds the target standard (i.e., *E. coli* CFU per 100 ml >1 for Australian standard, *E. coli* CFU per 100 ml >126 for US EPA standard), it was labeled as 1 (i.e., positive sample), otherwise 0 (i.e., negative sample). Applying the WE. coli_L1 standard, there were 18 (23.7%) and 58 (76.3%) samples, below and above the threshold, respectively. When applying the WE. coli_L126 standard, 70 samples (92.2%) were below the threshold, and only 6 samples (7.8%) violated (i.e., exceeded) the standard. The imbalance class distribution is a common property of fecal indicator bacteria (FIB) classification, and requires classifiers to properly handle imbalance data sets (Paule-Mercado et al. 2016). The proportion of violated samples for different standards ranged from 8.1 to 58.7% in the previous studies of FIB classification (Mas and Ahlfeld 2007; Motamarri and Boccelli 2012; Francey et al. 2006). The class imbalance was compensated through the modeling approach, as explained in Tousi et al. (2021b).

After enumerating *E. coli* in the sediment, d50 of sediments were determined through sieve and hydrometer analysis of the samples. Then, the shear velocity was calculated using the logarithmic velocity law by Eq. (1):

$$\frac{V}{u_*} = \frac{1}{\kappa}(\ln\frac{h}{k} - 1) + A_r \qquad (1)$$

where A_r = constant of integration, equal to 8.5; K = von-Karman constant, equal to 0.41; h = water depth (m), V = velocity (m/s), and k = roughness height (mm), approximately equal to the sediment size d50. The dimensionless bed shear stress on bed surface was calculated by Eq. (2) (Zhou et al. 2017; Tousi et al. 2020) using shear velocity and the size of sediment.

$$\tau_* = \frac{\rho_w u_*^2}{(\rho_s - \rho_w) g d_{50}} \quad (2)$$

where u*= shear velocity, ρ_w = water density (kg/m3); ρ_s = sediment density (kg/m3); g = gravitational acceleration (m/s2); and d50 = medium diameter of sediment (m). **Table 1** summarizes the descriptive statistics of these features along with the corresponding unit and notation. Among them, the three features characterizing sediment are median sediment size, nondimensional shear stress, and *E. coli* concentration in sediment.

Machine learning method to determine significance of *E. coli* in sediments on irrigation water quality

Five steps were used to evaluate the influences of sediment features (i.e., SE. coli, d50) on classifying *E. coli* levels in irrigation water. First, the key features among 13 measured variables were identified with respect to two standard levels (i.e., WE. coli_L1, WE. coli_L126). Two series of feature sets, including and excluding sediment features were selected. Then, the dimensionality reduction technique was used to visualize data in fewer dimensions. Third, three machine learning (ML) models were selected, and each model was trained over two feature sets: one including the sediment features, and the other one excluding these features. Fourth, all the modeling parameters were tuned using the 5-fold stratified cross validation (CV) method. The best performed models were selected based on validation scores. Last, the importance of all the selected features in the models were evaluated using the Kolmogorov-Smirnov (K-S) test. Details of each step can be found in Tousi et al. (2021b).

Application of machine learning to assess the importance of sediments and environmental factors in predicting *E. coli* levels in irrigation canal water - methods

A goal of this project was to determine the impact of sediments on the occurrence of *E. coli* in the overlaying irrigation water in irrigation canals in Arizona. To accomplish this goal, machine learning was used to evaluate several variables that could influence the role of sediments targeting its impact on two levels of *E. coli* in the irrigation water that have been suggested as potential standards. With this objective in mind, we evaluated the impact of incorporating sediment characteristics on improving the performance of machine learning models to quantify *E. coli* levels in irrigation water. Field samples were collected from irrigation canals in the Southwest U.S., for assessment of meteorological, chemical, and physical water quality variables as well as three additional flow and sediment properties: the concentration of *E. coli* in sediment, sediment median size, and bed shear stress. Water quality was classified based on *E. coli* concentration exceeding two standard levels: 1 *E. coli* and 126 *E. coli* colony forming units (CFU) per 100 ml of irrigation water. The correlation analysis revealed the inclusion of sediment features improves the correlation with the target standards compared to the models excluding these features. Support vector machine, logistic regression, and ridge classifier were tested in this study. The support vector machine model performed the best for both targeted standards. Incorporating sediment features improved the ability of predicting the level of *E. coli* in the water. The concentration of *E. coli* in sediment and bed shear stress were major factors influencing *E. coli* concentration in irrigation water. These results demonstrate the role of *E. coli* in the sediment in influencing the levels of *E. coli* in the irrigation water. In addition, elevated water temperatures and turbidity of the irrigation water were related to the levels of *E. coli*.

Results

Flume experiments - Viruses

The goal of the flume experiments was to determine the impact of sediment type (loam, sandy loam, sand) and virus type on the resuspension. Viruses and bacteria vary in surface properties and this can influence their association with solids in sediments. MS2 coliphage is the most hydrophobic non-enveloped virus and phiX174 is one of the more hydrophilic viruses (Shields and Farah 2002) and they were selected to represent the range of properties of viruses associated with foodborne outbreaks (i.e., norovirus, hepatitis A virus). Results revealed that the resuspension rate increases with the dimensionless bed shear stress. Based on these results, for the first time, we proposed two models to correlate the concentration of phiX174 with the dimensionless bed shear stress for different sediments. One model, proposed for sandy loam and loam, was verified favorably by the experimental data, and yielded a Nash-Sutcliffe efficiency coefficient (NSE) of 0.71 and R^2 value of 0.72. The other model was proposed for sand, and yielded an NSE of 0.20 and R^2 value of 0.26. Details of the models can be found in Tousi et al. (2021a).

Figure 2 shows the concentration of phiX174 in the water and nondimensional bed shear stress for all three types of sediment. The general trend indicated higher virus concentrations at higher bed shear stress for all sediments, yet there were differences for different sediments. Loam had the least scatter data compared with data for sandy loam and sand. For sand, when the nondimensional shear stress was less than 0.1, the virus concentration was almost constant, whereas at larger shear stress, the concentration increased rapidly. This phenomenon is attributed to the fact that the viruses are resuspended through the diffusion processes when the shear stress is less than the critical value. When the shear stress exceeds the critical value, virus resuspension is accompanied by intense sediment transport by flow, causing a sharp increase in the concentration. Moreover, because of sediment transport at high shear stress, viruses trapped in the bottom layer of sediment will exchange with sediment on the surface layer, facilitate a new source of viruses being released from sediment, and consequently increase its concentration in the water body. A similar pattern for sand sediment was observed for loam, but due to high critical shear stress resulting from the high clay percentage in loam, there is no obvious sharp increase in the virus concentration. In a similar manner, sandy loam shows the same behavior as loam and sand, yet due to the high heterogeneity of the sediment, it cannot be clearly seen because the data is highly scattered. The application of these models also indicated viruses are more easily resuspended from sand than sandy loam or loam sediments.

Figure 3 compares the results obtained with MS2 and phiX174 vs nondimensional sheer stress. These results suggest that phiX174 was resuspended to a greater degree than MS2, which may be associated with a lower degree of adsorption to the sediment for phiX174 than for the more hydrophobic MS2. Thus, the resuspension of viruses from sediments is dependent not only on flow properties but also on the type of virus.

Flume experiments - Bacteria

Both and *E. coli* and *Listeria monocytogenes* may be present in aquatic sediments. Three types of sediments were studied under different flow conditions (e.g., flow rate, velocity, shear stress). Results revealed that resuspension increases with the sediment bed shear stress (**Figure 4** and **Figure 5**, respectively). Two empirical relations were proposed to correlate the concentration of *E. coli* and *Listeria* with the dimensionless bed shear stress. The models for sandy loam, loamy sand and loam were verified favorably by the flume experimental data. The results showed that bacteria can be resuspended from sand more easily than from sandy loam or loam sediments. The relationships can be applied to water quality model to simulate *E. coli* and *L. monocytogenes* transport in water and sediment, and can be used as a predictive tool for management of irrigation water quality.

Field studies

Table 2 shows the water quality values and sediment parameters studied. *E. coli* levels in the sediment varied widely from one location to the other, from a minimum of 1.7 MPN/100 g to 176,623.9 MPN/100 g. Of interest was that the greatest concentrations were found in the sediments of diversion boxes (splitter boxes). The concentration of *E. coli* in splitter boxes was 10 to >1,000 times greater than in the sediments of the irrigation canals. This finding suggests that sediments in these structures may be potential reservoirs of *E. coli* and other microorganisms. Although *Listeria* species were common in sediments and in the water, no *Listeria monocytogenes* were confirmed by molecular methods of identification.

Machine learning models were applied to determine if incorporating sediment information will improve the prediction of *E. coli* concentration in irrigation water. Principal component analysis showed that samples exceeding *E. coli* greater than 126/100 ml were clustered closer to each other than samples exceeding *E. coli* greater than 1/100 ml which makes the classification task easier for the *E. coli* 126/100 ml standard. The correlation analysis found that the included sediment properties have stronger correlations with *E. coli* levels (**Figure 6**). Overall, incorporating sediment parameters improved the models' performance. These results demonstrate that bed shear stress and the concentration of *E. coli* in sediments influence *E. coli* contamination in irrigation water.

Outcomes and Accomplishments

1. It was demonstrated that *E. coli* in sediments in irrigation canals will impact the occurrence of *E. coli* in the overlaying water with a standard of 126 *E. coli* /100 ml for irrigation waters.
2. Neither irrigation water nor sediments are a source of *L. monocytogenes* in irrigation canals in Arizona.
3. Models were developed to predict the impact of flow conditions and sediment type on resuspension of *E. coli, L. monocytogenes* and viruses. These models can be used to minimize contamination of the irrigation water through appropriate management.

Summary of Findings and Recommendations

1. Virus resuspension from sediment was found to vary with the type of virus. Thus, foodborne viruses, such as norovirus and hepatitis A virus, may have different potentials for contaminating the overlaying water.
2. Models were developed to predict the resuspension of viruses, *E. coli* and L. *monocytogenes* based on microorganism type, sediment type, flow rate, velocity, and shear stress. These models can be used to predict the impact of these microorganisms in sediment in the overlaying water under varied operational conditions during irrigation events.
3. Data collected in field studies was analyzed using machine learning and it was found that *E. coli* in the sediments influences the quality of the irrigation water in canal systems if the standard is 126 *E. coli* /100 ml.
4. No *L. monocytogenes* was detected in the sediments or water of irrigation canals in Arizona, and do not appear to be a source in this region.
5. The highest concentrations of *E. coli* in sediments were found in those of splitter boxes (diversion boxes), and these could potentially be reservoirs of *E. coli* in irrigation systems. These concentrations were 10 to >1,000 times greater than those found in canal sediments. Splitter boxes should be studied to determine their impact on irrigation water quality.
6. Sediments collected repeatedly from some locations always had high concentrations of *E. coli*. These may be point sources of *E. coli* contamination of the overlaying water. Studies should be conducted to determine why these locations always have high levels of *E. coli* in the sediment. *E. coli* in the sediment could be an indicator of long-term *E. coli* concentrations in the water.

APPENDICES

Publications

Tousi, E. G. 2020. Experimental Study of Pathogenic Microorganism Resuspension from Mobile Bed Sediment in Irrigational Canals. PhD Dissertation. University of Arizona. http://hdl.handle.net/10150/656757.

Tousi, E. G., J. G. Duan, P. M. Gundy, K. R. Bright, and C. P. Gerba. 2021. Experimental study of phiX174 resuspension from mobile bed sediment. Journal of Irrigation and Drainage Engineering 147:0421009. DOI:10.1061/(ASCE)IR.1943-4774.0001549.

Publications submitted or in preparation
Tousi, E. G., J. G. Duan, P. M. Gundy, K. R. Bright, and C. P. Gerba. Evaluation of *E. coli* in sediment for assessing irrigation water quality using machine learning. *Submitted.*

Tousi, E. G., J. G. Duan, P. M. Gundy, K. R. Bright, and C. P. Gerba. Experimental study of *E. coli* and *Listeria* resuspension from mobile bed sediment. *In preparation.*

Presentations

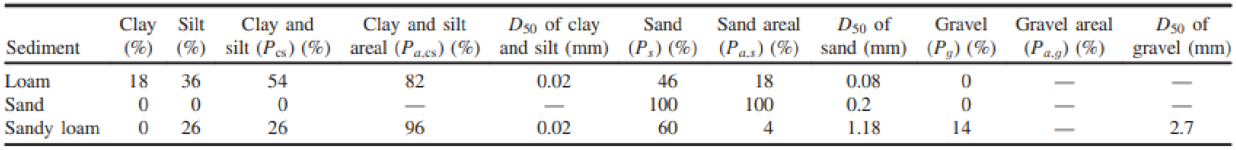
1. "Development of a model to predict the impact of sediments on microbial irrigation water quality." Centre for Produce Safety Research Symposium, 2019. Austin, TX. [Poster]
2. "Development of a model to predict the impact of sediments on microbial irrigation water quality." Presented by Kelly Bright. CPS Research Symposium Webinar Series V. [Online]

Budget Summary

The total of research funds awarded was $148,563. Funding expended through March 31, 2021, includes approximately $28,403 in materials and supplies, $7,809 in travel expenses (gasoline, hotels, per diem) for field sampling and one trip by the PI to attend the 2019 CPS Annual Research Symposium, $99,721 in personnel costs, and $6,686 in indirect costs for a total of $142,619 spent. Since the annual CPS Research Symposium was attended remotely in 2020 and will be again in 2021, most of the remaining unspent budget ($5,644 of the $5,944 remaining funds) are from these unused travel funds.

Tables 1–2 and Figures 1–6

Table 1. Sediment composition



Sediment	Clay (%)	Silt (%)	Clay and silt (P_{cs}) (%)	Clay and silt areal ($P_{a,cs}$) (%)	D_{50} of clay and silt (mm)	Sand (P_s) (%)	Sand areal ($P_{a,s}$) (%)	D_{50} of sand (mm)	Gravel (P_g) (%)	Gravel areal ($P_{a,g}$) (%)	D_{50} of gravel (mm)
Loam	18	36	54	82	0.02	46	18	0.08	0	—	—
Sand	0	0	0	—	—	100	100	0.2	0	—	—
Sandy loam	0	26	26	96	0.02	60	4	1.18	14	—	2.7

Table 2. Water quality and characteristics of irrigation canals

Variable	Notation/ Acronym	Unit	Min	Max	Mean	Standard deviation
Water temperature	Wtemp	°C	10.0	36.9	21.4	6.8
Air temperature	Atemp	°C	8.1	47	26.1	10
Relative humidity	RH	%	8	77.1	29	16.4
pH	-		8	9.7	8.6	0.3
Salinity	-	ppm	341	691	573.4	54.3
Conductivity	-	µS/cm	485	1416	1151.3	133.9
Total dissolved solid	TDS	ppm	512	1000	821.2	78.7
Turbidity	-	NTU	0.8	25.5	5.1	5.1
Sediment median size	d_{50}	mm	0	2.3	0.4	0.6
Non-dimensional bed shear stress	τ_*	-	0	0.7	0.1	0.1
Flow velocity	V	m/s	0	0.7	0.3	0.2
Flow depth	h	m	0.1	3.3	1.3	0.7
E. coli in sediment	SE. *coli*	*E. coli*/100 g total dry solid	1.7	176623.9	4827.9	20688.2

1

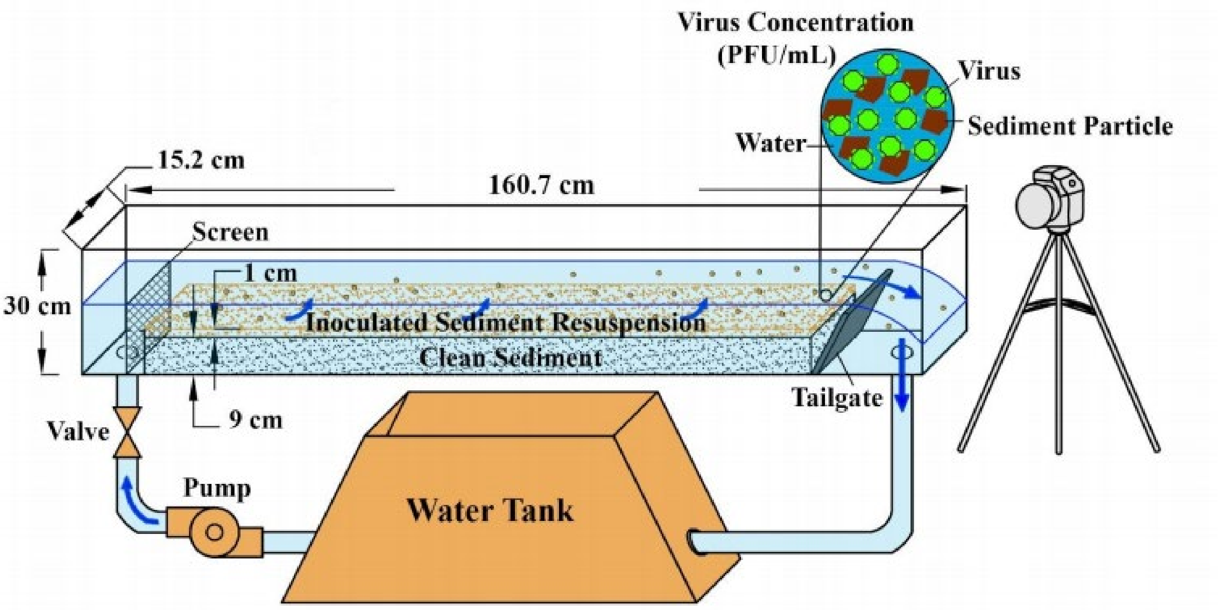


Figure 1 Sketch of the experimental flume

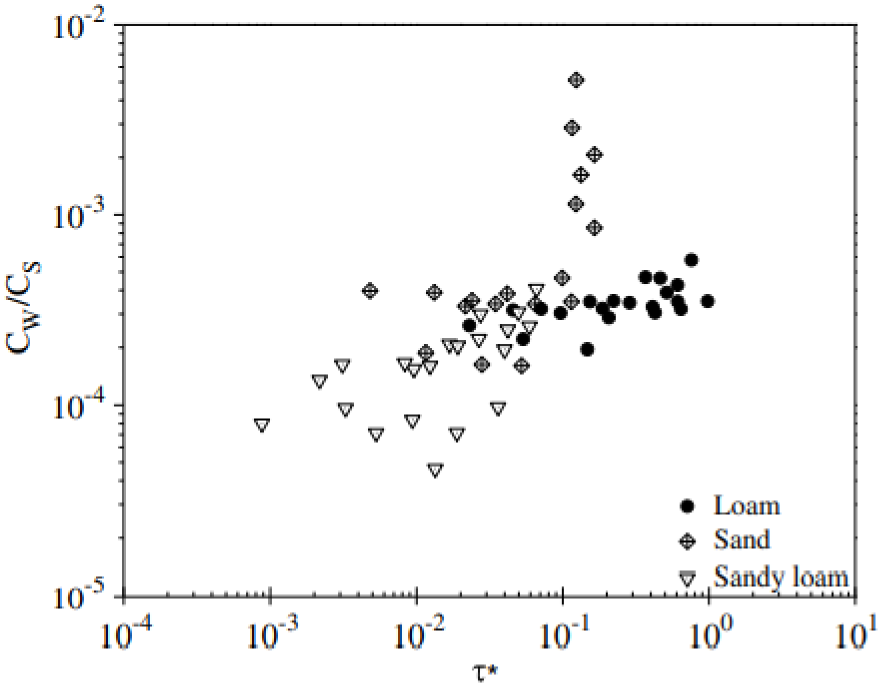


Figure 2. PhiX174 concentration in water and sediment versus nondimensional bed shear stress. T*= bed shear stress; C_w/C_s = concentration of virus in water/sediment concentration of virus in sediment.

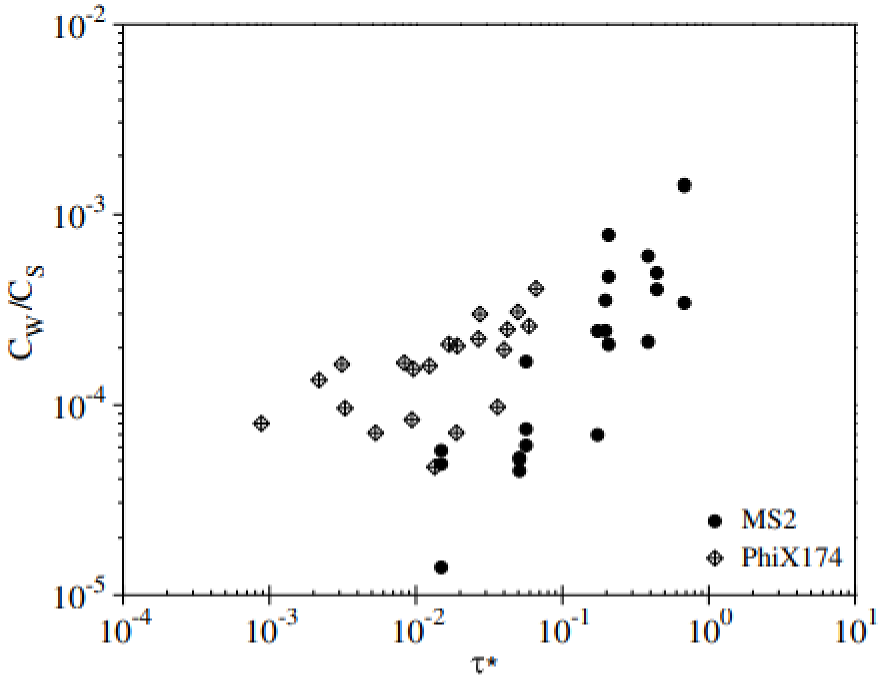


Figure 3. PhiX174 and MS2 concentration in water and sediment versus nondimensional bed shear stress. t*= bed shear stress; Cw/Cs = concentration of virus in water/ concentration of virus in sediment.

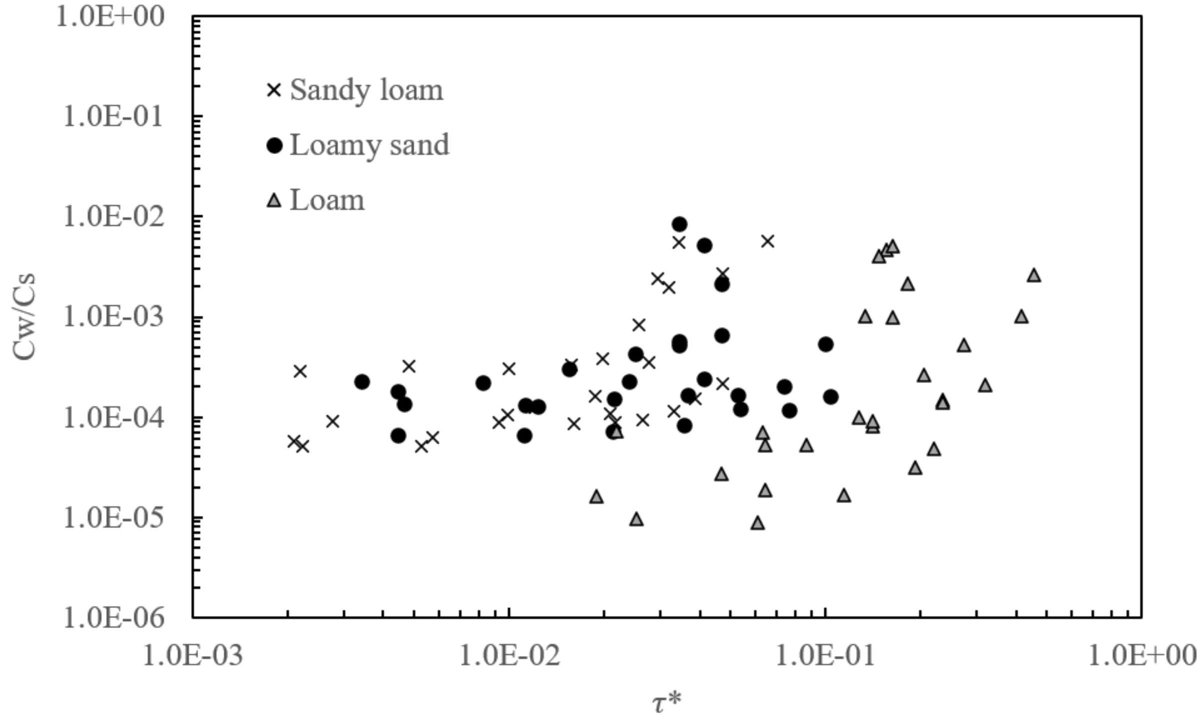


Figure 4. *E. coli* concentration in water and sediment versus nondimensional bed shear stress. t*= bed shear stress; Cw/Cs = concentration of virus in water/ concentration of virus in sediment.

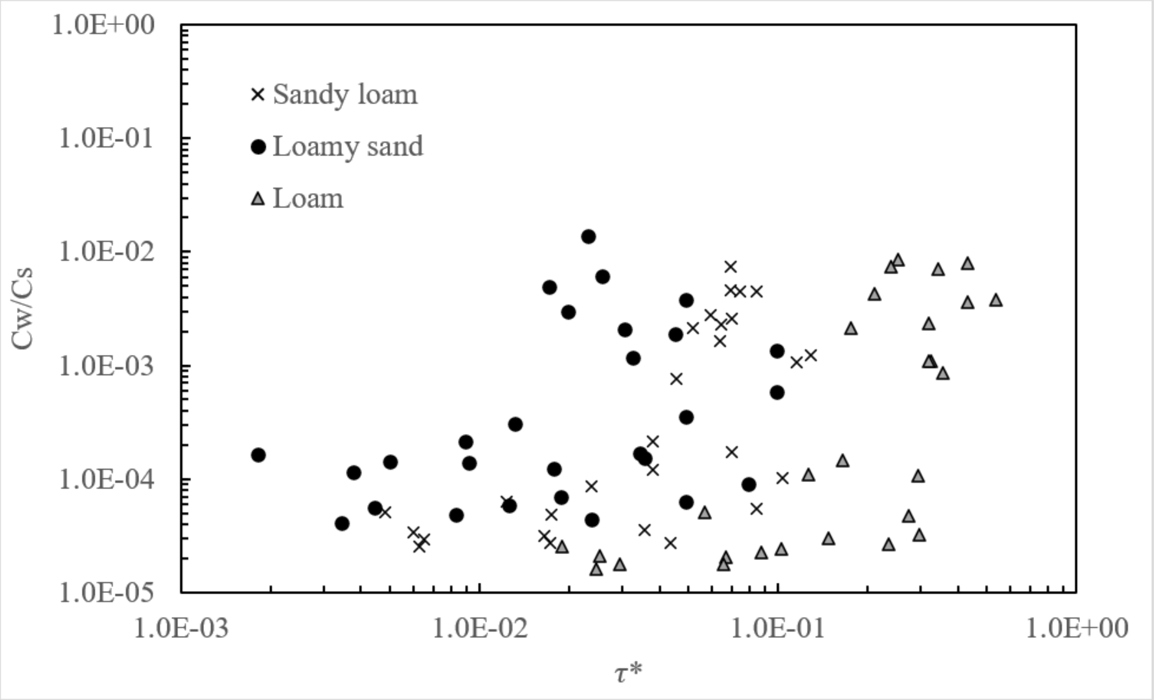


Figure 5. *L. monocytogenes* concentration in water and sediment versus nondimensional bed shear stress. t*= bed shear stress; Cw/Cs = concentration of virus in water/ concentration of virus in sediment.

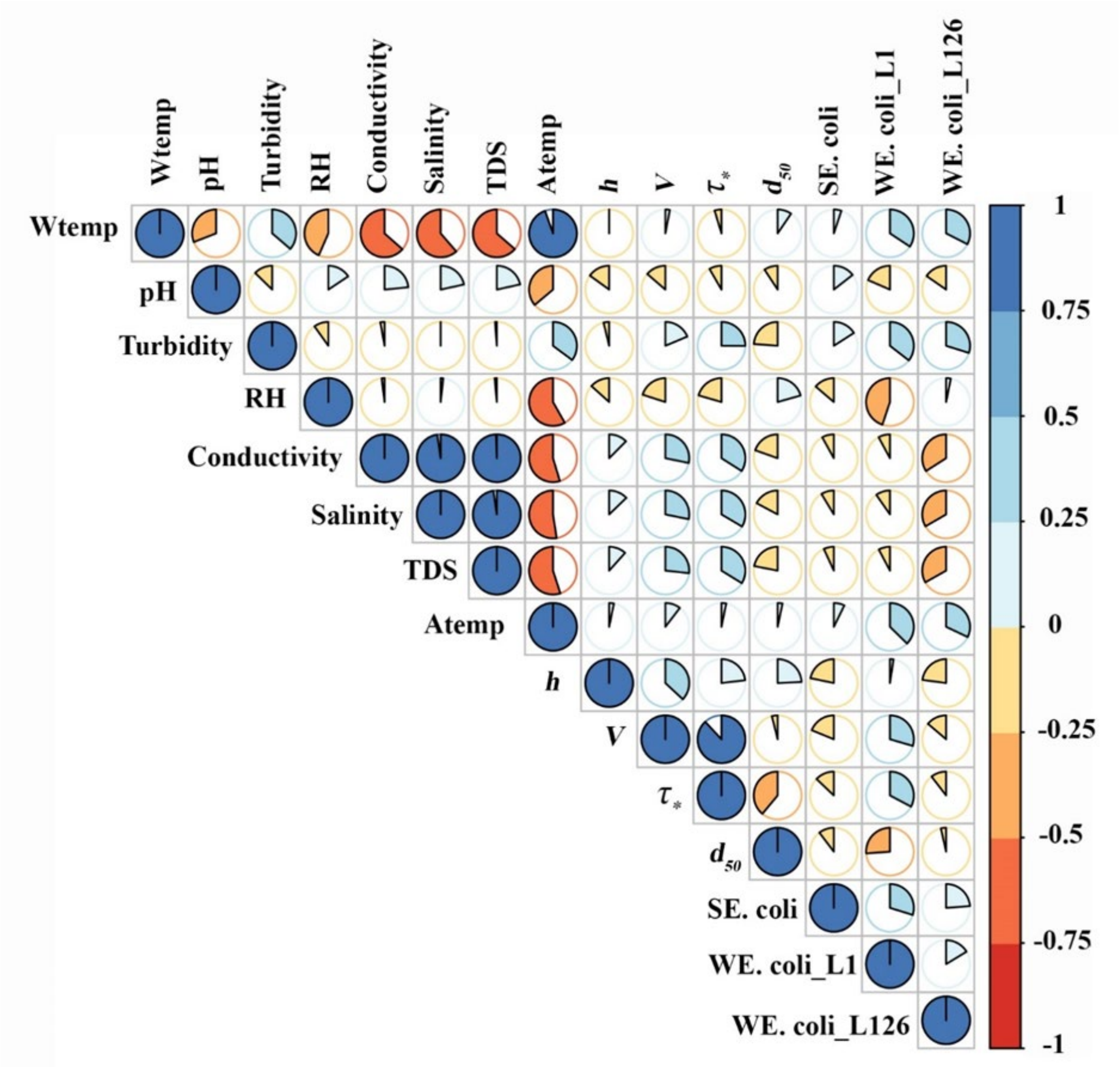


Figure 6. Correlation plot of water quality/sediment parameters in relation to a standard of 1 *E. coli*/100 ml and 126 *E. coli*/100 ml. The colored scale at the right indicates if the correlation is positive or negative (1 = 100% positive correlation and -1 = 100% negative correlation). The circle filling indicates the degree of correlation (the more the circle is filled the greater the degree of correlation: for example, water temperature [Atemp] is strongly positively correlated (as air temperature increases so does the water temperature Wtemp). Wtemp – water temperature, Atemp – air temperature, RH – relative humidity, TDS – total dissolved solids, h – flow depth, V – flow velocity, τ*– dimensionless shear stress, d50 – sediment median size, SE.coli – *E. coli* in sediment CFU/100g , WE.coli_L1 – E. coli in water more than 1 CFU/100 ml, WE.coli_L126 – E. coli in water more than 126 CFU/100 ml.

References cited:

Ashbolt, N.J. et al. 2010. Water Res. 44:4692-4703.

Bai, S. and Lung, W.S. 2005. Water Res. 39:5232-5240.

Collins, R. and Rutherford, K. 2004. Water Res. 38:700-712.

Davies, C.M. et al. 1995. Appl. Environ. Microbiol. 61:1888-1896.

de Brauwere, A. et al. 2014. Critical Rev. Environ. Sci. Technol. 44:2380-2453.

Eleria, A. and Vogel, R.M., 2005. J. Am. Water Resour. Assoc. 41:1195–1209. https://doi.org/10.1111/j.1752-1688.2005.tb03794.

Francy, D.S. et al. 2013. Appl. Environ. Microbiol. 79:1676–1688. https://doi.org/10.1128/AEM.02995-12

Gerba, C.P. and Kayed, D. 2003. J. Food Sci. 68:1136-1142.

Gerba, C.P. and McLeod, J. 1976. Appl. Environ. Microbiol. 32:114-120.

Hassard, F. et al. 2016. Frontiers in Microbiol. 7, 1692.

Jamieson, R.C. et al. 2005. J. Enviro. Qual. 34:581-589.

Jurzik, I. et al. 2010. Intl. J. Hyg. Environ. Hlth. 213:210-216.

Lopman, B. et al. 2012. Curr. Opinions in Virology. 2:96-102.

Mas, D.M.L. and Ahlfeld, D.P. 2007. Hydrol. Sci. J. 52, 713–731. https://doi.org/10.1623/hysj.52.4.713.

Monnier. A.L. et al. 2011. J. Clin. Microbiol. 49:3917-3923.

Motamarri, S. and Boccelli, D.L. 2012. Water Res. 46, 4508–4520. https://doi.org/10.1016/j.watres.2012.05.02.

Pachepsky, Y.A. and Shelton, D.R. 2011. Critical Rev. Environ. Sci. Technol. 41:1067-1110.

Paule-Mercado, M.A. et al. 2016. Sci. Total Environ. 550, 1171–1181. https://doi.org/10.1016/j.scitotenv.2016.01.026.

Sanders, B.F. et al. 2005. Water Res. 39:3394-3408.

Shields, P.A. and Farrah, S. R. 2002. Appl. Environ. Microbiol. 68:3965-3968.

Shields, P.A. and Farrah, S.R. 2002. Appl. Environ. Microbiol. 68:3965-3968.

Taylor, E. V. et al. 2010. J. Food Protect. 76:939-944.

Tian, Y.Q. et al. 2002. J. Environ. Qual. 31:860-869.

Tousi, E.G. et al. 2021a. J. Irrig. Drain. Eng. 147:0421009. DOI:10.1061/(ASCE)IR.1943-4774.0001549.

Tousi, E.G. et al. 2021b. Evaluation of *E. coli* in Sediment for Assessing Irrigation Water Quality using Machine Learning. *Submitted for publication.*

USDA. United States Department of Agriculture. 1987. “Soil mechanics. Level 1: Module 3-USDA textural sol classification study guide. Technical Report. National Soil Conservation Service (NRCS). Washington, DC.

Walter, W.G. 1961. Standard methods for the examination of water and wastewater. (11th ed.). American Journal of Public Health and the Nation’s Health, 51. p. 940

Wu, J. et al. 2009. J. Water Resources Assoc. 45:35-44.

Zhou, K. et al. 2017. J. Irrig. Drain Eng. 143: 04017005.