A Mechanistic Bacterial Transport Model to Inform Food Safety Management of Agricultural Pond Water

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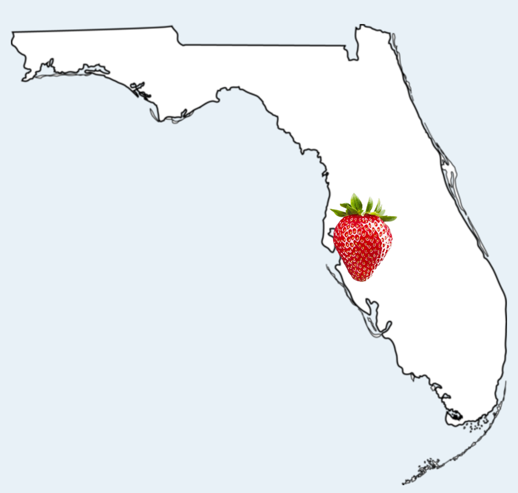
Irrigation water is considered a major pathway to fresh produce for foodborne-illness related bacterial pathogens, but sampling-based regulations fail to fully control highly variable irrigation ponds.[1,2]

New food safety regulations (FSMA) use a sampling-based approach, using *Escherichia coli* as an indicator organism to regulate surface water used for irrigation[1]. It has been shown that in irrigation ponds with high *E. coli* variability, a limited sampling scheme can under- or over-estimate criteria used to monitor these ponds, leading to increased food safety risk or additional costs to the growers.[2]

The study area

The data were collected from an irrigation pond used for strawberry production in West Central Florida during two winter growing seasons, 2012-2013, and 2013-2014.



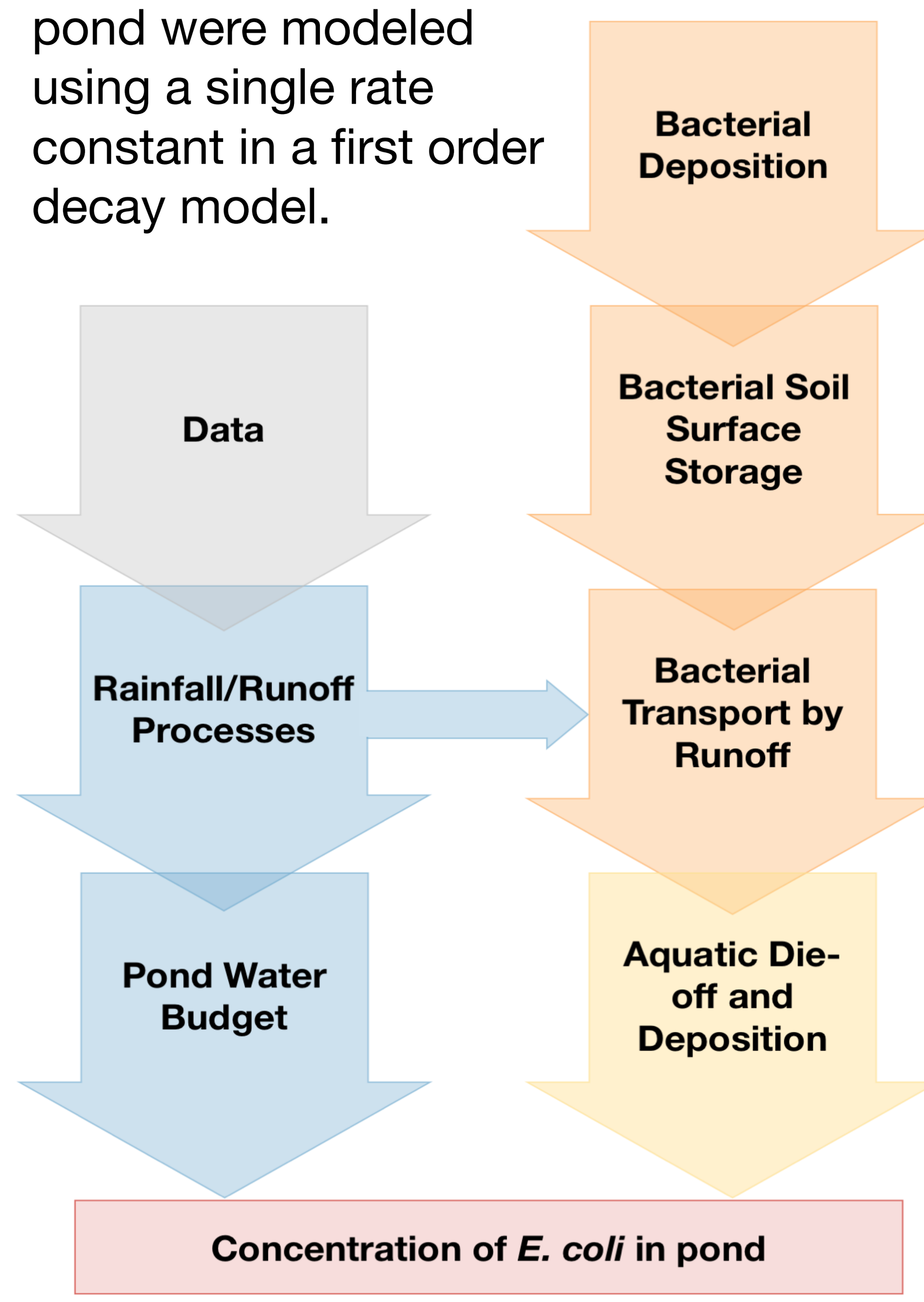
Mulch
Black plastic mulch is used to prevent weed growth and warm the soil in the cooler months. It also promotes runoff.

Wildlife
Populations of wildlife on the land appear to be the only source of fecal bacteria contamination.

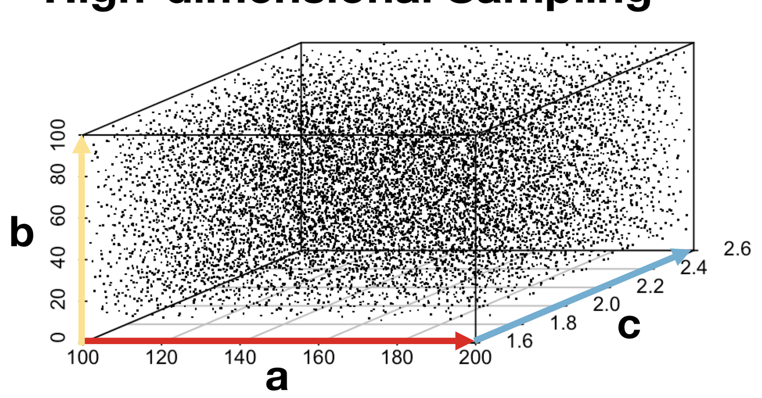
Drains
Runoff is collected at the edge of adjacent fields and routed to the pond using drains and culverts.

Towards a Mechanistic Understanding

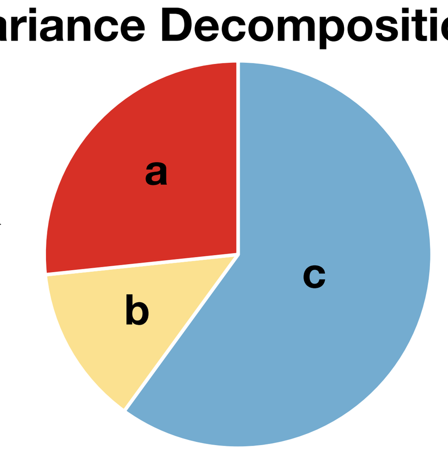
To better understand irrigation ponds with highly variable *E. coli* levels, a mechanistic model was developed with the goal of being **parsimonious**, **competitively accurate**, and with a focus on predicting the **timing of peak concentration events**. Bacterial accumulation was modeled as populations of wildlife on the land. The NRCS curve number method was used to model rainfall and runoff processes[4]. Both die-off and deposition of bacteria in the pond were modeled using a single rate constant in a first order decay model.



High-dimensional Sampling



Variance Decomposition

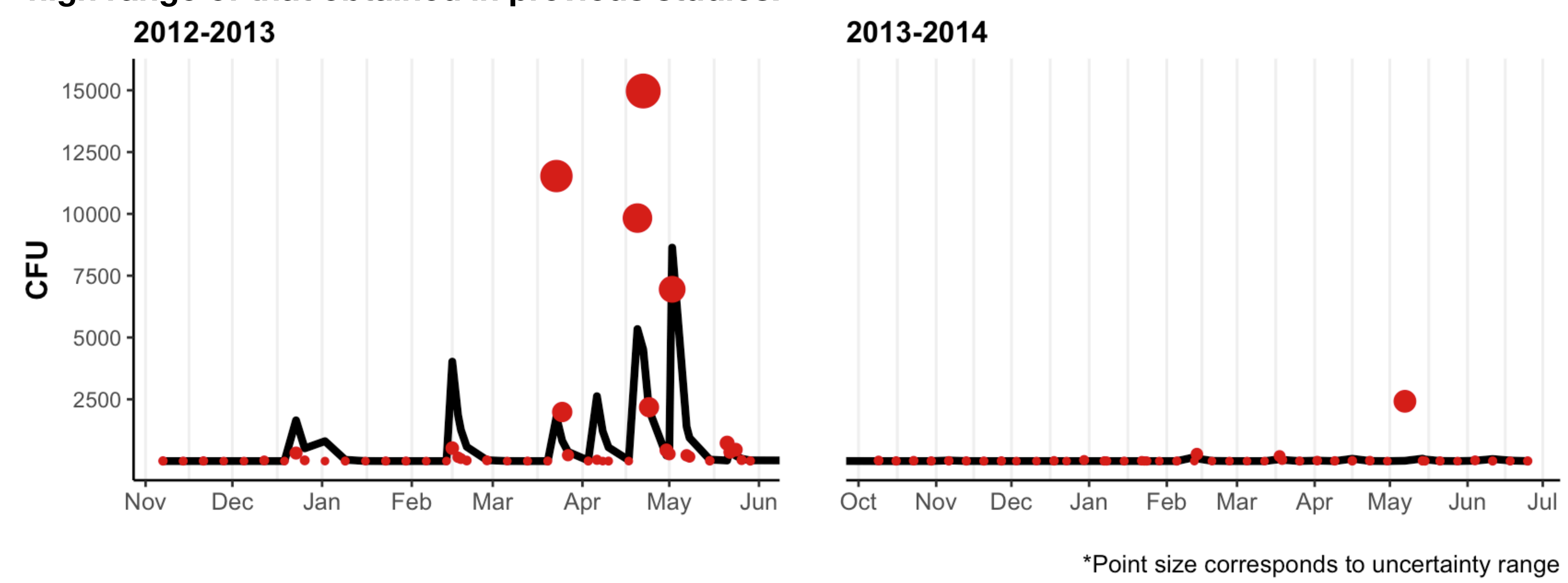


Global Sensitivity Analysis

Global sensitivity analysis[8] was used on the model to quantify the effects of each parameter on the variance of the geometric mean **(measure of mean bacterial contamination, GM)** and statistical threshold value **(measure of peak bacterial contamination, STV)** of the predicted data set. These results were used to reveal methods for controlling food safety risk in irrigation ponds, with a focus on preventative measures.

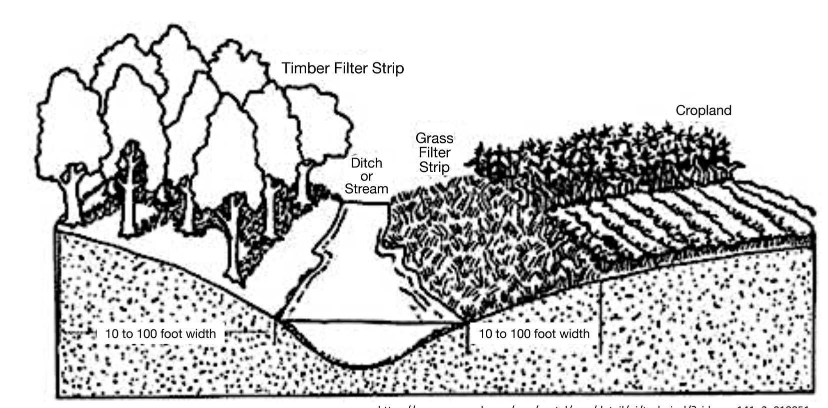
Model Performance

The performance of the model was similar or superior to existing pathogen transport models, with a **Nash-Sutcliffe efficiency (NSE) of 0.455** when incorporating observed value uncertainty.[5] Previous studies[6,7] using industry standard models to predict bacterial concentrations found that many were not able to produce NSE values above 0.387. Thus, a NSE=0.455 is **considered competitive and in the high range of that obtained in previous studies.**

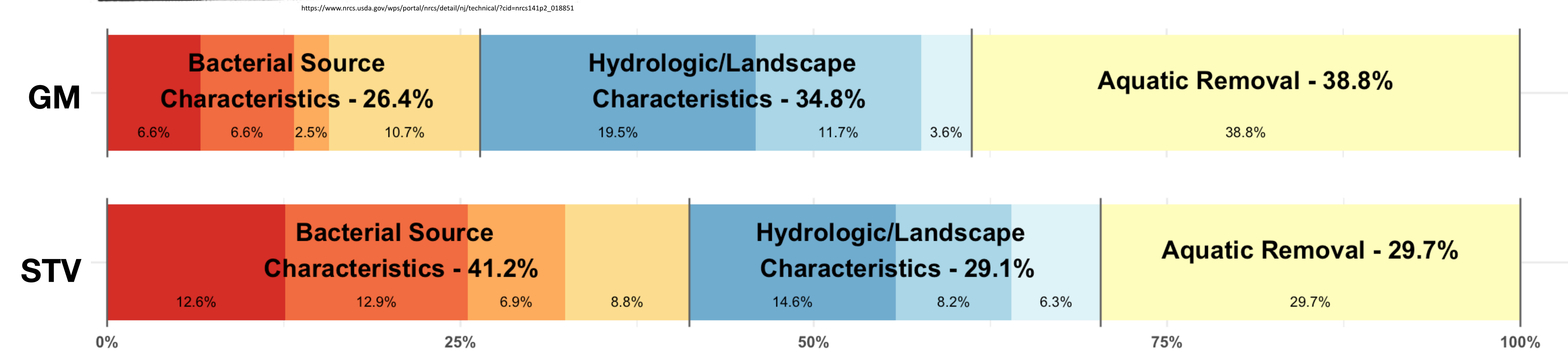


*Point size corresponds to uncertainty range

Preventative controls are viable for reducing mean contamination, while an altered sampling schedule might better control peaks.



Controlling the mean
Hydrologic/Landscape characteristics were found to control a large portion of the GM variance. Therefore, we recommend altering the landscape to prevent transport through the use of vegetative filter strips. Vegetative filter strips promote settling of contaminants and can reduce overall levels of bacteria transported to the pond. [9]



Controlling the peaks
Exclusion of bacterial sources, such as wildlife, livestock, pets, and human waste, from the areas draining to agricultural ponds should be a focus of growers with noncompliant STV values. Because peaks are also controlled by runoff, a hydrologic characteristic, sampling schedules that take advantage of this knowledge to control high-risk peak contamination events through treatment or alternative water sources are recommended.

Feces produced per day | Bacterial density of feces | Population, 2014–2015 | Population, 2013–2014 | Curve number, soil | Curve number, mulch | Washoff coefficient | Aquatic removal rate constant