Pathogen Impairments in Iowa and the United States

- Pathogens are the leading cause of water quality impairments in Iowa
- 10,674 pathogen impaired waters in the U.S.
- Causes of waterborne disease outbreaks resulting in gastroenteritis
- 900,000 illnesses and 900 deaths per year in the U.S. 1.8 million diarrhea-related fatalities annually

Ref: Warrington, 2001
WHO, 2004
Pathogens are a leading cause of water quality impairments in the United States

- Develop TMDLs for impaired waters “considering all sources of pollution”

Figures by Kevin Brannan, Virginia Tech

Factors to consider when modeling in-stream bacteria fate and transport.

- Pathogens are present in water systems and may preferentially attach to sediments
- They survive and persist in stream sediments
- They resuspend into the water column during high flows, contributing an additional source of bacteria
- Water quality models typically used to develop TMDLs do not account for many of the important processes.
**Goal:** Improve understanding of in-stream *E. coli* fate and transport.

**Work to date:**
- Flume experiments to measure the contributions of direct fecal deposits by cattle
- Collection of sediment and water samples in Squaw Creek
- Developing equations to predict the bacteria resuspension process
- Assessing the contributions of resuspended bacteria over a range of flows
- Relating in-stream *E. coli* levels to watershed properties and nutrient levels
- New work is examining the environmental and genetic factors driving *E. coli* attachment to particles

**Cattle are often allowed to have direct access to streams.**

*Image by S. Ranganath*
**HOW CAN WE STUDY THESE PROCESSES? IN A FLUME.**

1. Flume: 9.1 m long, 0.6 m wide, and 0.6 m deep
2. Collect samples at 1.66 m and 3.66 m downstream of deposition point over a range of flows
3. Sample 0.5, 5, 15, 30, and 60 m after deposition

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**E. coli CONTRIBUTIONS TO THE WATER COLUMN FROM DIRECT FECAL DEPOSITS**

1. Find a volunteer
2. a. Make a standard cowpie
   b. Measure its properties
   c. Toss it in the flume
3. Collect samples at two locations 0.5, 5, 15, 30, and 60 minutes after deposition

4. Measure velocity profiles

5. Enumerate attached and unattached *E. coli*

**VIDEO CLIPS**
A single cowpie can cause water quality standards to be exceeded to one hour after deposition.

Mcdaniel et al., 2013, JAWRA
Attached fractions averaged over four flows ranged from 28 to 12% and decreased with time.

McDaniel and Soupir, 2013, WASP

Next we began extensive monitoring of E. coli in the Squaw Creek Watershed

Study Area

Total area - 592 sq km
First order streams: 75
Main channel length - 60 km
Crop land area - 74%
CAFOs - 20
MEASUREMENTS

1) E. coli levels in water column, 2) E. coli levels in sediment and bank soils, 3) TSS, 4) grain size, 5) stream flow, 6) precipitation

STREAM BOTTOM SEDIMENTS ACT AS A RESERVOIR OF BACTERIA, WHICH ARE RESUSPENDED DURING HIGH FLOWS.

Bacteria concentrations in bottom sediments may be 10 to 10,000X higher than concentrations in overlying waters (Bai and Lung, 2005).
STUDY OBJECTIVES

- Investigate the impact of flow from a single storm on E. coli levels in the streambed sediment and overlying waters
- Modify sediment transport equations to predict the resuspension of E. coli in waters
- Compare the results to a mass balance model

SINGLE EVENT ANALYSIS: FLOW AND PRECIPITATION PATTERNS

Pandey and Soupir, Trans ASABE, in review
**SINGLE EVENT ANALYSIS: FLOW AND E. coli CONCENTRATION PATTERNS**

![Graph showing E. coli concentration patterns with flow (m$^3$/s) and time (hour) axes.](image)

Pandey and Soupir, Trans ASABE, in review

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**SINGLE EVENT ANALYSIS: E. coli RATIO BETWEEN WATER AND SEDIMENT**

![Graph showing E. coli ratio between water and sediment.](image)

Pandey and Soupir, Trans ASABE, in review
VARIATION IN STREAMBED SEDIMENT DURING A SINGLE EVENT

Greater proportions of fine particles, and \( D_{10} \)

NEXT WE MODIFIED SEDIMENT RESUSPENSION EQUATIONS TO REPRESENT ATTACHED OR UNATTACHED E. COLI

- Physically based
- Considers the effects of flow, sediment, and organism
- **Flow** represented by shear stress (function of flow rate, channel geometry and roughness of the bed)
- **Sediment** represented by critical shear stress (dependent upon sediment size, bulk density, clay fraction)
- **Organism** effects captured by critical shear stress for attached and unattached bacteria, concentrations in the sediment bed

\[
R_a = C_a E_{0a} \left( \frac{\tau - \tau_{cn}}{\tau_{cu} - \tau_{cn}} \right)^{n_a} \quad \text{and} \quad R_u = C_u E_{0u} \left( \frac{\tau}{\tau_{cu}} \right)^{n_u}
\]

Pandey et al., 2012, Water Research
Next, we compared the calculated resuspension rates to a mass balance model.

\[ R_d = k_w H_2 C_2 + f_a w_s C_1 \]

Pandey et al., 2012, Water Research

Predicted resuspension rates vs. those measured through the mass balance model.

Pandey et al., 2012, Water Research
ASSESSING THE IMPACTS OF STREAMBED TOTAL \textit{E. coli} LOADS UNDER VARIABLE FLOW AND SEDIMENT \textit{E. coli} LEVELS.

\[ P_{sw} = \frac{E \text{. coli sediment}}{E \text{. coli water}} \]

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{chart1.png}
\caption{E. coli loads at \( P_{sw} \) = 1, \( P_{sw} \) = 100, \( P_{sw} \) = 1,000, \( P_{sw} \) = 0. \( P_{sw} \) is the ratio of E. coli in sediment to E. coli in water.}
\end{figure}

RESULTS (SEDIMENT AND WATER \textit{E. coli} RATIO)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{chart2.png}
\caption{Ratio (E. coli in sediment/E. coli in water) measured over time.}
\end{figure}
RESULTS (PREDICTION VERIFICATIONS)

- Direct fecal deposits are a significant source of *E. coli* to streams
- *E. coli* levels in bank soils and streambed sediment samples are considerably higher than the overlying water samples.
- *E. coli* levels in the stream water column increase considerably during a single storm event (from 360 CFU/100 ml to 37,553 CFU/100 ml).
- Modified sediment resuspension equations predicted *E. coli* resuspension rates when compared to a mass balance model.
Next Steps

- Modified the Soil and Water Assessment Tool to include this process.
- Study the genetic and environmental factors driving *E. coli* attachment to particles
  - Collaborators: Dr. Laura Jarboe and Dr. Michael Thompson, Student: Xiao Liang, Chunyu Liao

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