Modeling In-stream bacteria Dynamics

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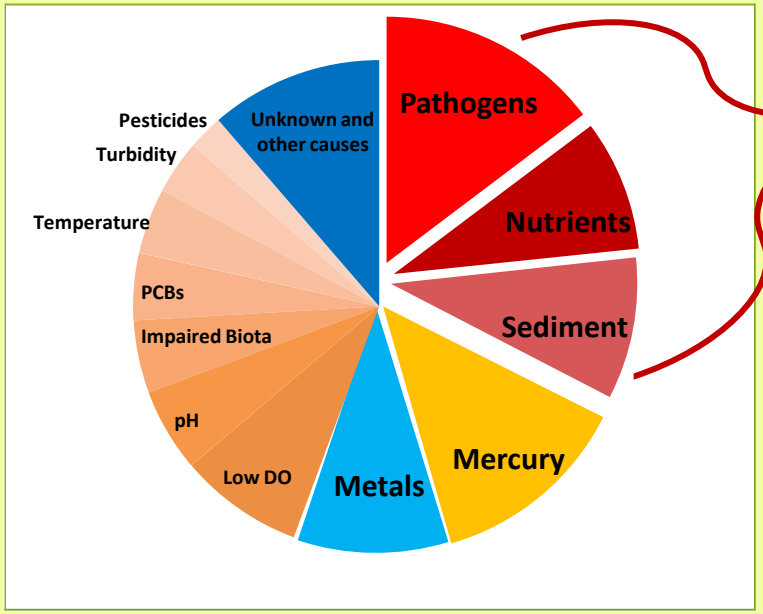
IMPAIRMENTS

EPA states: '..geometric mean should not exceed 126 E. coli CFU/100 ml during sampling over 1 month period.'

WHO states: '..there is no tolerable lower limit for pathogens for consumption, should thus contain no agents pathogenic for humans.'



Agriculture

Impairments in Region 7: Pathogenic water impairment 1st in Nebraska, 2nd in Iowa and Missouri

Status of Pathogen Impairments in US

Pathogenic water pollution in U.S. (USEPA, 2002a)

River and stream
- Impairment: 39% of assessed (19%)
- Source: Agriculture

Estuaries
- Impairment: 51% of assessed (36%)
- Source: Agriculture

Lakes, reservoirs, ponds
- Impairment: 45% of assessed (43%)
- Source: Agriculture

Great lakes shorelines
- Impairment: 78% of assessed (92%)
- Source: contaminated sediment

Ocean shorelines
- Impairment: 14% of assessed (6%)
- Source: Urban runoff/storm sewers

900, 000 cases of illness

900 deaths each year

Where do pathogens come from?

More natural

unnatural

http://greenerloudoun.wordpress.com/2009/02/16/thanks-for-the-free-cow-urine-in-my-drinking-water/

Where do pathogens come from?

http://www.motherjones.com/files/legacy/mojoblog/funny-cats-a10.jpg

Hypothesis & Objectives

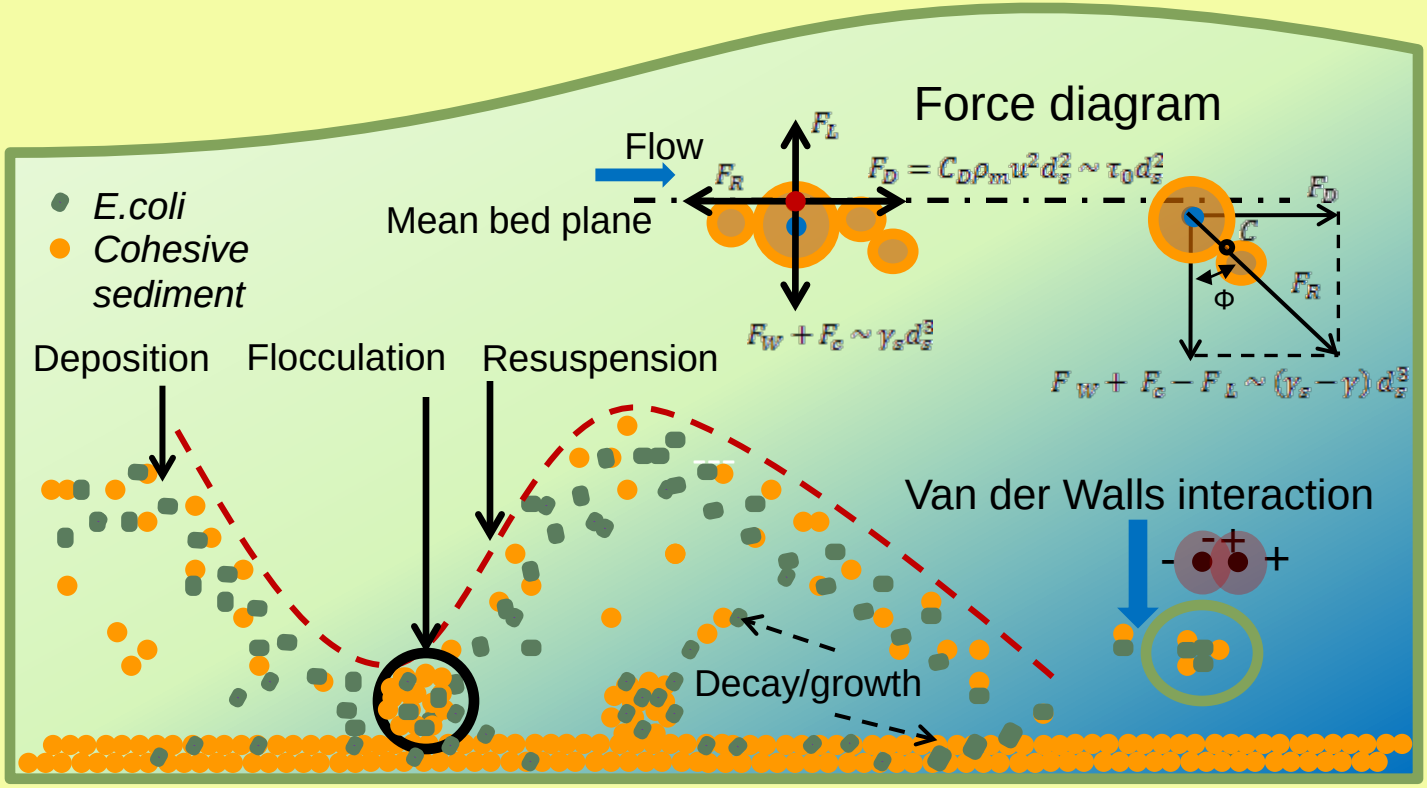
Hypothesis: Bacteria movement in clay-water interactive cohesive environemnt is not clearly understood, which is main obstacles in modeling in-stream pathogen transport. Noting the similarity between cohesive particles and bacteria physical properties : sizes ≈ 2 μm ; Reynolds number ≤ 1; Van der Walls attractive forces, our hypothesis is that the fundamental physics involved in bacteria transport should remain same as in water-borne cohesive particle movements. Threshold conditions for the incipient transport of bacteria in stream should be similar to that for the incipient transport of cohesive particles. Hydrodynamic (lift and drag) and cohesive (lift resistance) forces should be predominant causes for deposition and resuspension of bacteria in stream.

Objectives:

- To develop a model for pathogen deposition, resuspension and death/growth in stream environment
- Validate the model for watershed scale

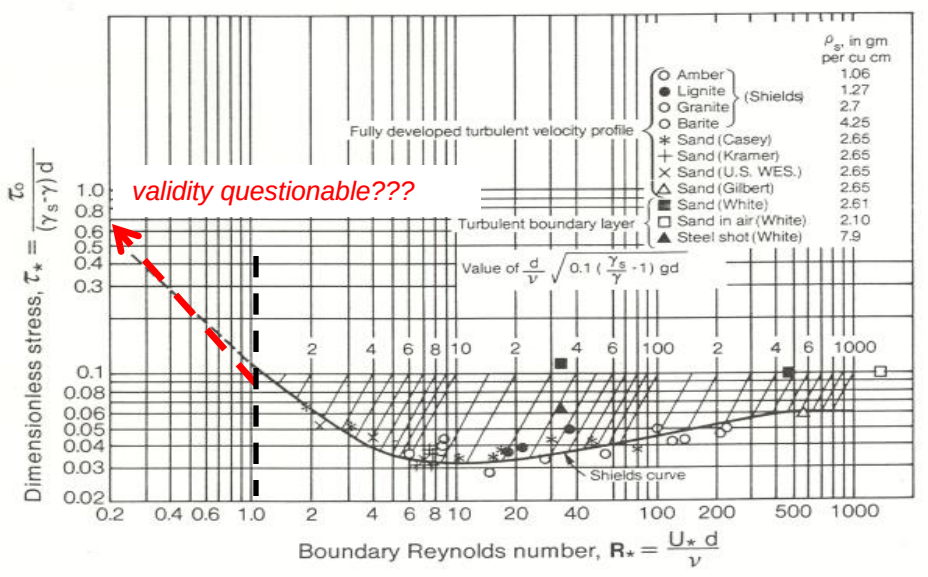
Conceptual model

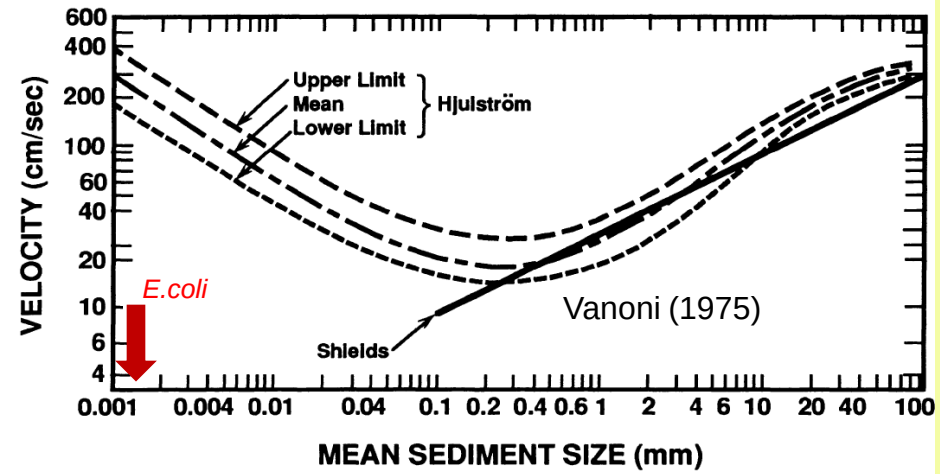
Conceptual model was developed for delineating the domains of bacteria transport in stream with water-borne cohesive sediment

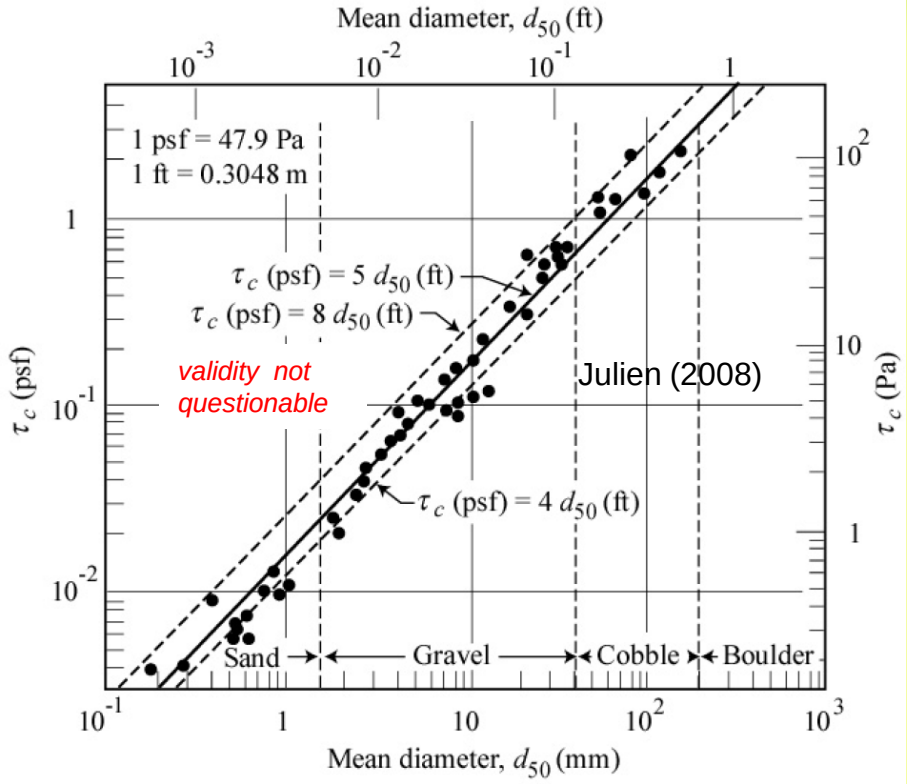


Methodologies

Shields Diagram (1936): Shows the conditions for the beginning of sediment motion. Relates the dimensionless shear stress with the particle Reynolds number







Problems: performance for smaller particles
Solutions: empirical approach

METHODOLOGIES CONTINUED…

Empirical approach

$$\tau_c = \frac{C_2(F_c+F_g)}{C_1 d^2}$$

$$\tau_c = \left(1+\frac{ae^{bp}}{d^2}\right)\tau_{cn}$$

$C_1 = \pi\rho_w C_d/8C$ $\quad C_2 = constant$ $\quad F_g = gravitational\ force$ $\quad F_c = cohesive\ force$

$\tau_c = critical\ shear\ stress\ at\ cohesive\ and\ gravitational\ forces$

For all size ranges

$$E = 10^{-4}\left(\frac{\tau-\tau_{cn}}{\tau_c-\tau_{cn}}\right)^n$$

Semi - empirical approach

Shields parameter

Cohesive parameter

$$\frac{\tau_{cs}}{g(\rho_{sf}-\rho)d} = \frac{\alpha_3 \tan\phi}{(\alpha_1+\alpha_2\tan\phi)} + \frac{F_c\tan\phi/(\alpha_1+\alpha_2\tan\phi)}{g(\rho_{sf}-\rho)d^3}$$

$\emptyset = Repose\ angle$

Problems: **in constants and cohesive force estimation**

Solutions: **strong sensitivity analysis**

Methodologies continued…

Strokes law: settling velocity

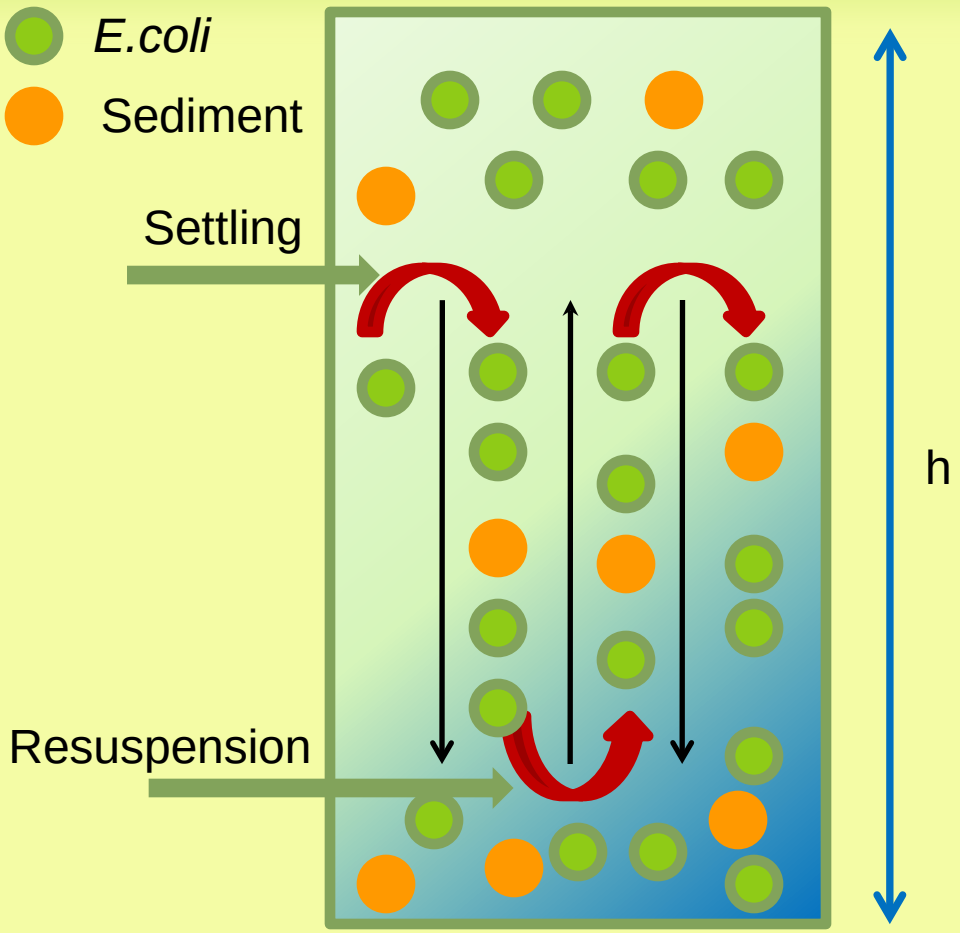
$$\omega = \frac{g(G-1)d_s^2}{18\,\vartheta}$$

Validity for silt & clay

$$\omega = \sqrt{\frac{4\,g(G-1)d_s}{3\,C_D}}$$

Validity for gravels & cobbles

Settling



Current status of model

In developing stage in excel using the macro functionality

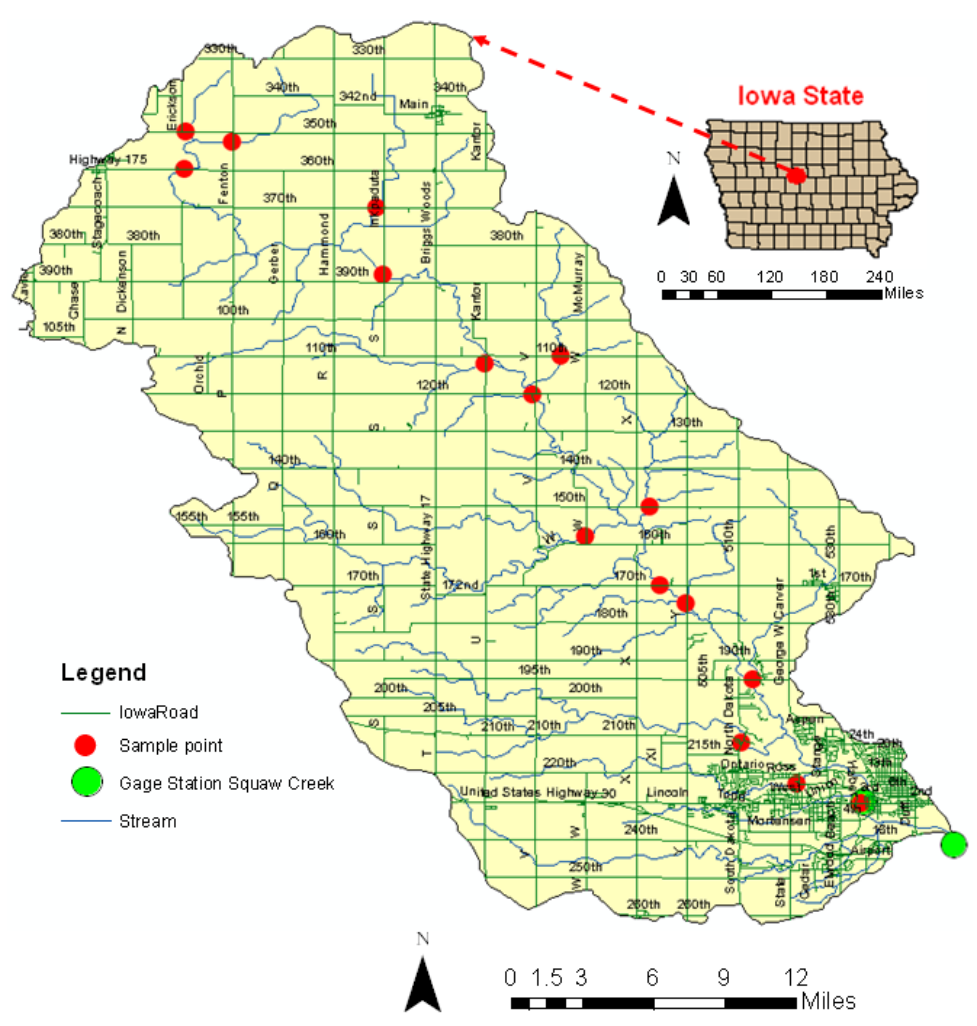
H29

	A	B	C
1	Input parameters and constants		
2	Name	Values	Units
3	**Resuspension parameters**		
4	a	8.50E-15	m^2
5	b	9.07	cm^3/g
6	n_a	2.13	constants
7	E_{0a}	9.90E-06	m/s
8	**E. coli parameters**		
9	H_2	0.02	m
10	f_a	1	
11	**Constants & coefficients**		
12	g	9.81	
13	ρ	998	
14	ν	1.00E-06	(m^2/s)
15	**River properties**		
16	z	2	(Hor:Ver)
17	ρ_b	1.27	g/cm^3
18	s	2.65	s
19	Q	3.6	m^3/s
20	n	0.035	n
21	**Net growth rate**		
22	k_{gmax}	2.4	d^{-1}
23	C_{T1}	0.08	constants
24	C_{T2}	0.1	constants
25	T_{min}	0.08	Deg C
26	T_{max}	0.1	Deg C
27	θ_M	1.11	constants

	E	F	G	H	I
					Cal
					0
	Sensitivity analysis				
	Sensivity Resuspension Parameters				Clear resuspension sensivity data
	Parameters	Base value	Range 1	Range 2	Steps
	a	8.50E-16	8.50E-25	8.50E-15	8.50E-15
	b	9.07	8	10	0.1
	na	2.13	1	3	0.1
	E_{0a}	1.00E-06	1.00E-08	1.00E-04	1.00E-06
	Sensivity Bulk Density				Clear bulk density sensitivity data
	ρ_b	1.27	1.19	1.75	0.01
	Sensivity river parameters				Clear river sensitivity data
	s	2.65	1	6	0.01
	n	0.04	0.01	0.1	0.01
	Sensivity net growth parameters				Clear net growth sensitivity data
	k_{gmax}	2.4	1	4	0.01
	CT1	0.08	0	0.8	0.01
	CT2	0.1	0.01	0.9	0.01
	θ_M	1.11	0.5	2	0.05
	k_{d20}	0.48	0.05	1	0.01
	Sensivity Ecoli Parameters				Clear river sensitivity data
	H_2	0.02	0.005	0.08	0.005
	f_a	1	0.1	1	0.01

	L	M	N	O	P	Q	R	S	T	U
	Nomenclature									
	A	Cross sectional area of the stream								
	a	Coefficient in Lick's formula for critical shear stress								
	B	Bottom width of the stream								
	b	Coefficient in Lick's formula for critical shear stress								
	C_a	Concentration of attached bacteria in the sediment								
	C_{T1}	Coefficient in the formula for the temperature dependence of growth (Hipsey et al. 2008)								
	C_{T2}	Coefficient in the formula for the temperature dependence of growth (Hipsey et al. 2008)								
	C_1	Concentration of bacteria in th			8.1	0	0.00	0	0	
	C_2	Concentration of bacteria in the sediment								
	d	Sediment diameter								
	E_{0a}	Coefficient in the formula for resuspension of attached bacteria								
	f_a	Attached fraction								
	g	Acceleration of gravity								
	H_2	Depth of sediment containing bacteria								
	h	Water depth								
	k_d	Decay rate of bacteria								
	k_{d20}	Dark death rate of bacteria at 20 deg C								
	k_g	Growth rate of bacteria								
	k_{gmax}	Growth rate of bacteria at 20 deg C with no nutrient limitation								
	k_{n2}	Net growth rate in the sediment								
	n	Manning coefficient								
	n_a	Exponent in the resuspension formula for attached bacteria								
	P	Wetted perimeter								
	R	Hydraulic radius								
	R_{ap}	Resuspension rate of attached bacteria predicted by formula								
	R_{a1Dm}	Resuspension rate of attached bacteria inferred from a 1D model								

Study area for Model validation



Study Area
Squaw Creek Watershed

Sampling
16 locations

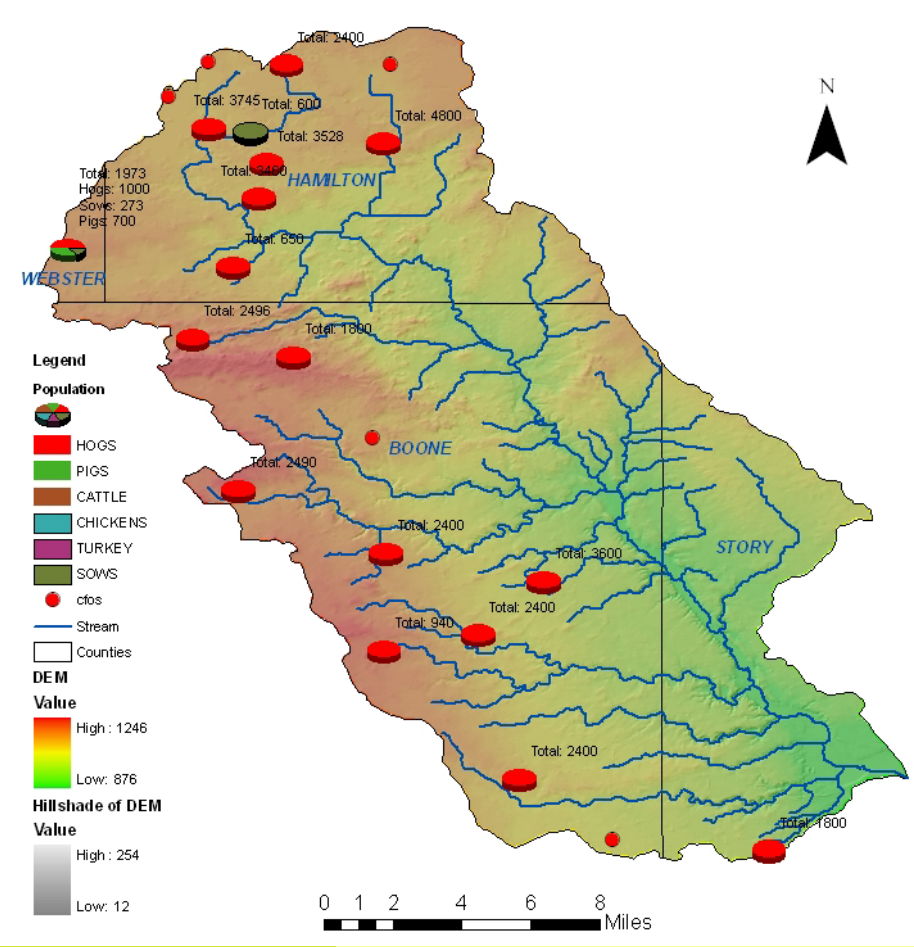
Samples
Water, sediment, bank soils

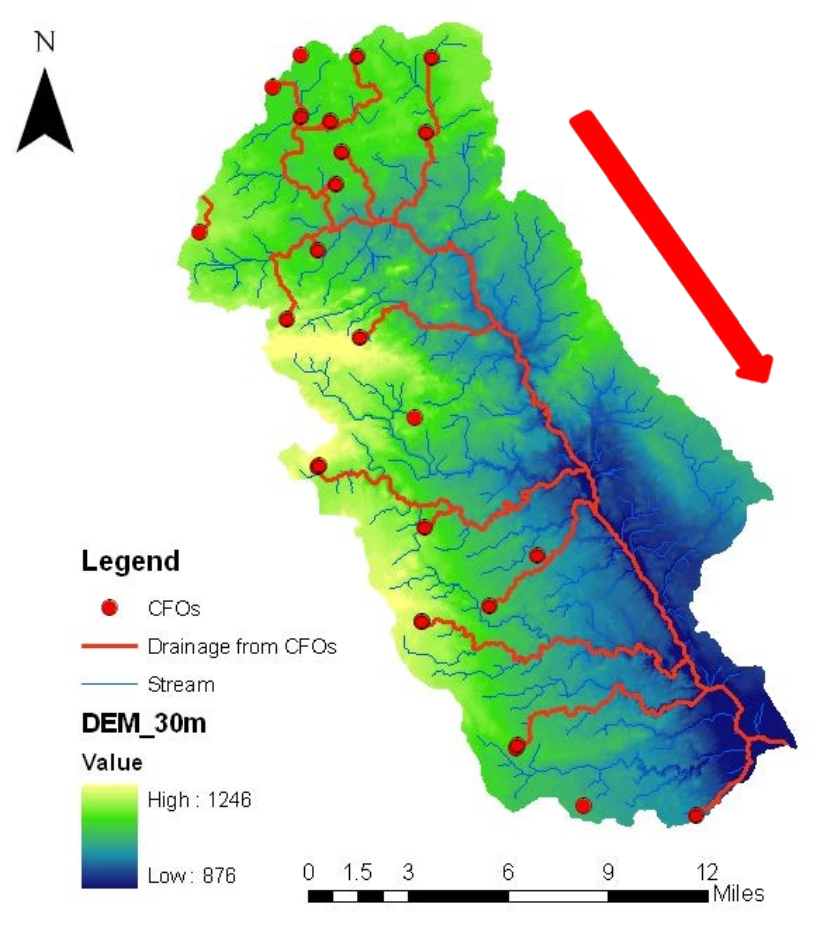
In-situ measurements
Temp, DO, TDS, pH

Lab measurements
E.coli, TSS, Turbidity, grain size, chemical characteristics of samples

WATERSHED CHARACTERISTICS

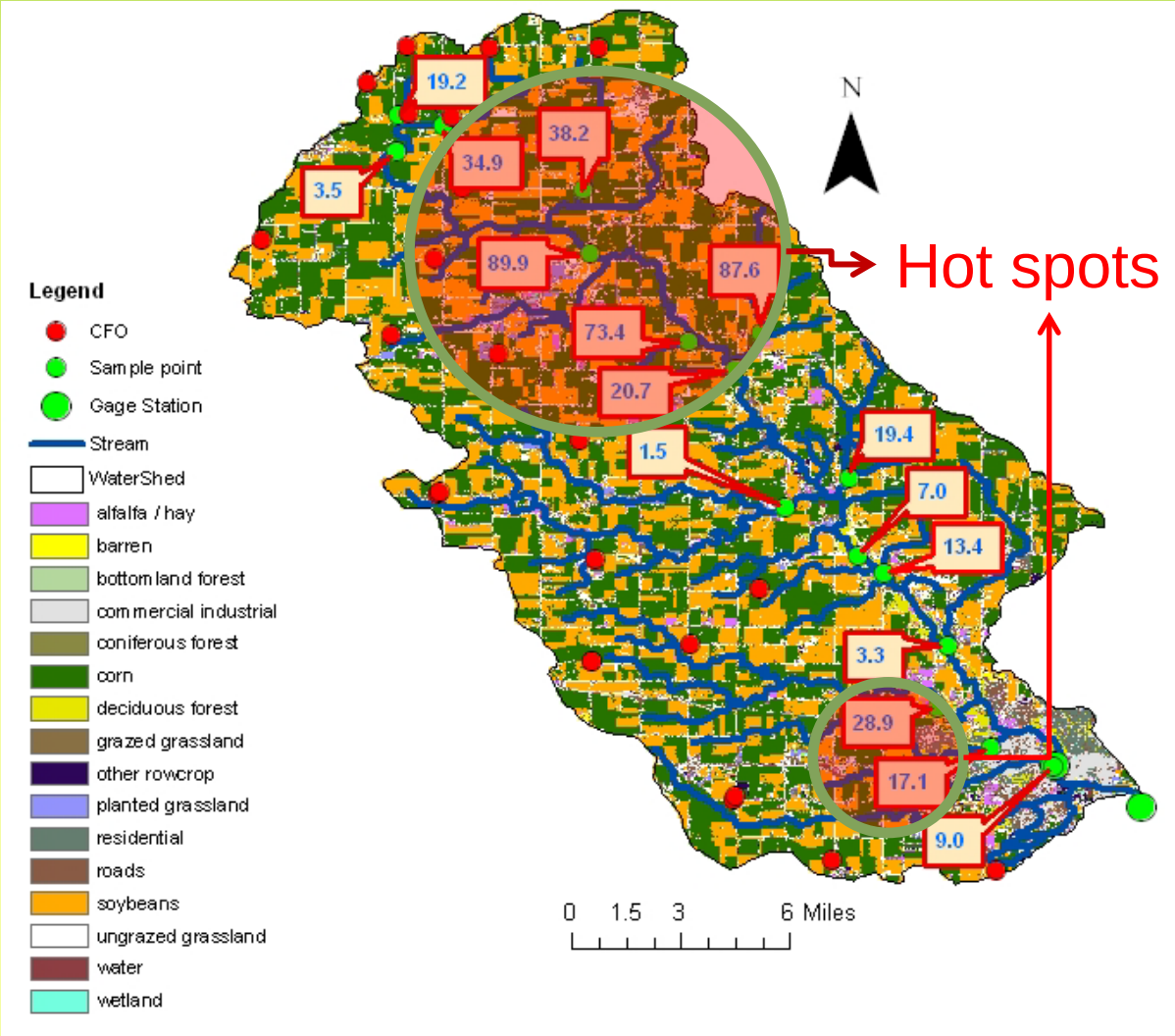
Confined feeding operation units (CFOs) locations (left) and flow path from CFOs (right)



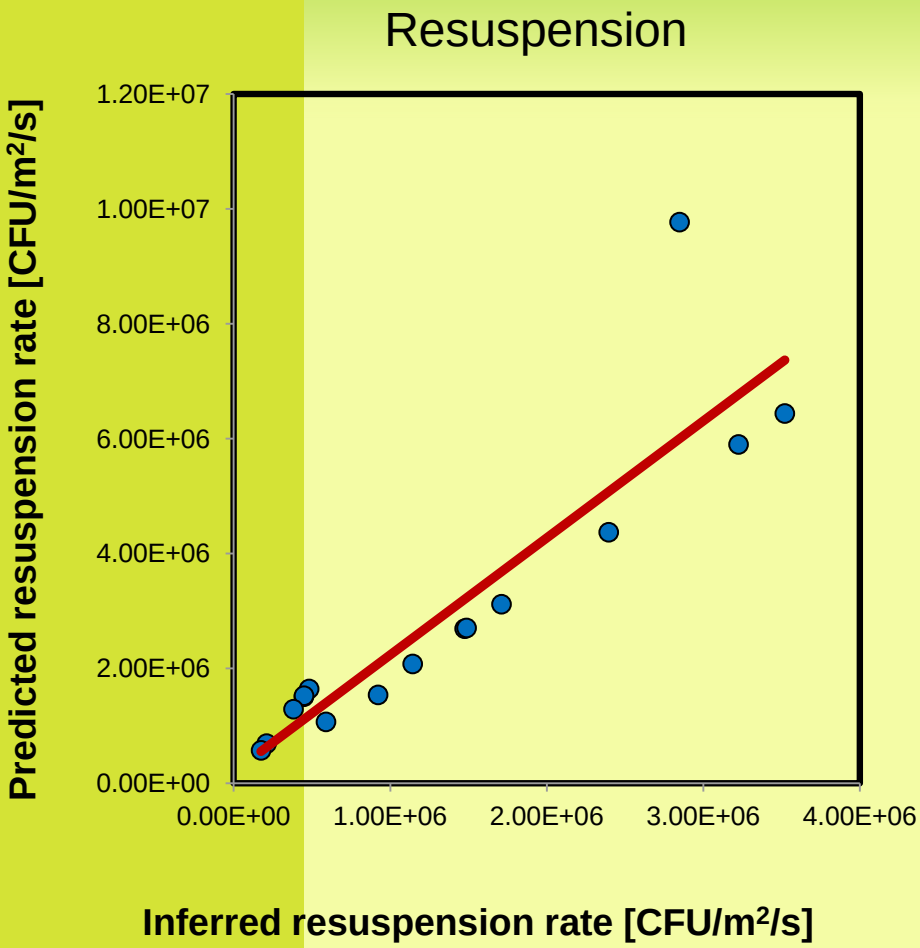


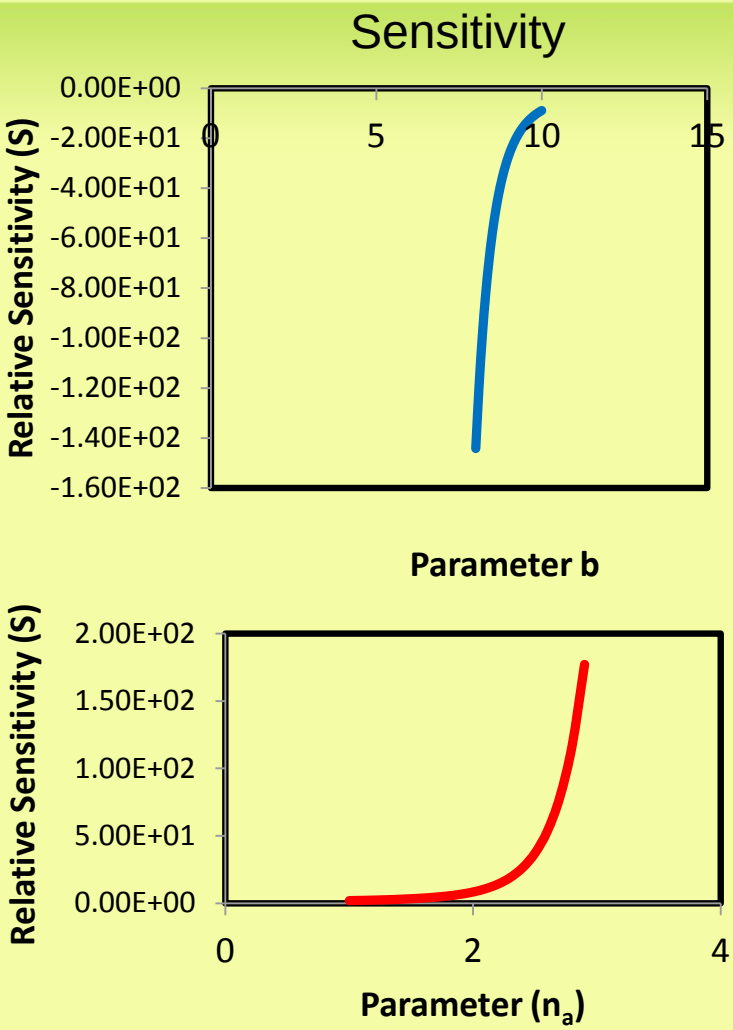
RESULTS

E.coli ratio between sediment and water



RESULTS….


Resuspension
Predicted resuspension rate [CFU/m²/s]
1.20E+07
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06
Inferred resuspension rate [CFU/m²/s]


Sensitivity
Relative Sensitivity (S)
0.00E+00
-2.00E+01
-4.00E+01
-6.00E+01
-8.00E+01
-1.00E+02
-1.20E+02
-1.40E+02
-1.60E+02
0
5
10
15
Parameter b
Relative Sensitivity (S)
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
0
2
4
Parameter (n_a)

Plan of Future work

- Use about 2 years data to validate the model for current study area
- Compare the results with reported study
- Finally develop a module to include in Soil Water Assessment Tools (SWAT) model

Questions?

Image by S. Ranganath