Modeling approach on resuspension of *E. coli* from streambed using Soil and Water Assessment Tool (SWAT)

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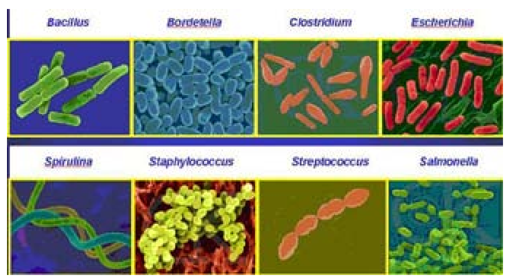
Outline

1. Introduction
2. Modeling Study on Fecal Indicator Bacteria
3. Modeling Approach using SWAT
4. Modeling Results
5. Conclusion

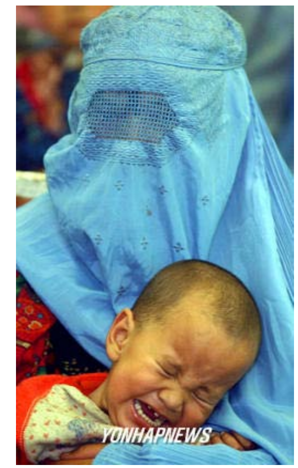
Introduction

Introduction

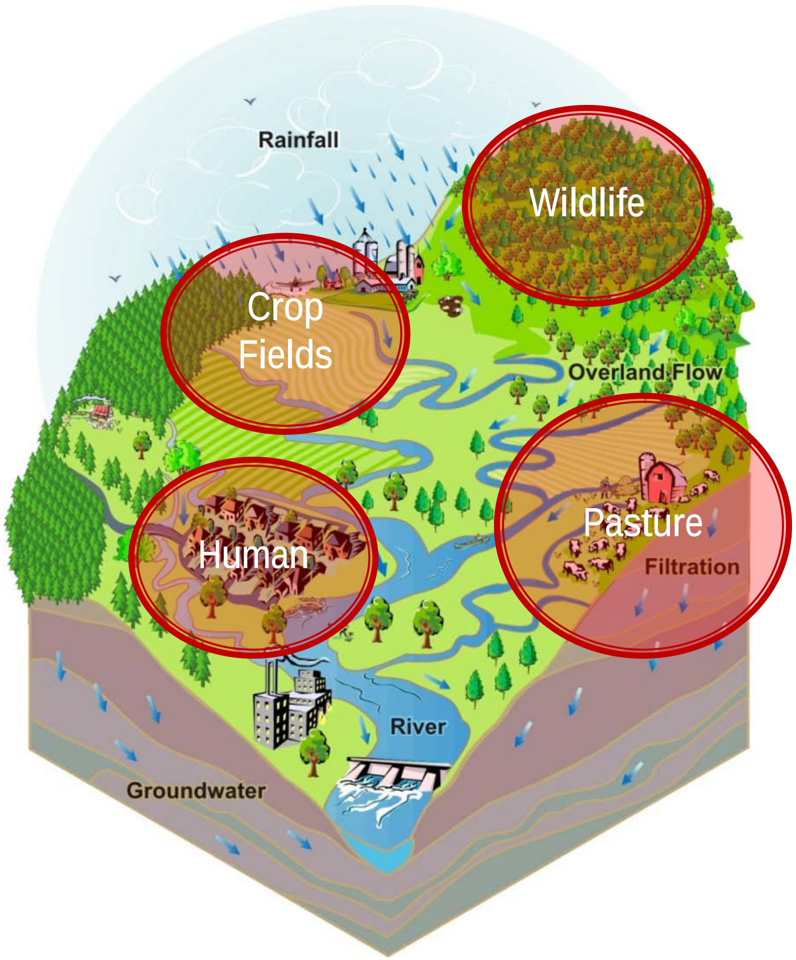
- Can we predict Fecal Indicator Bacteria (FIB) in natural surface waters ?



www.worstpolluted.org/projects_reports/display/57



Introduction



Source: http://www.awag.org/Education/Watershed_diagram.jpg

1. Several studies have investigated the sources, fate, and transport of FIB in waterbodies, and have revealed that the levels of FIB are significantly influenced by meteorological conditions (e.g., the solar intensity during dry weather)

2. Nonpoint sources such as soil leaching, surface runoff, and manure runoff have been considered important contributors to the fecal contamination of receiving waterbodies

3. Another potential source during wet weather is the resuspension of FIB from the sediment bed, where FIB is 1–3 orders of magnitude greater than that of the water column

➔ Understanding of the diverse fate and transport behavior of fecal-borne microorganisms is critical for public health risk assessment and management.

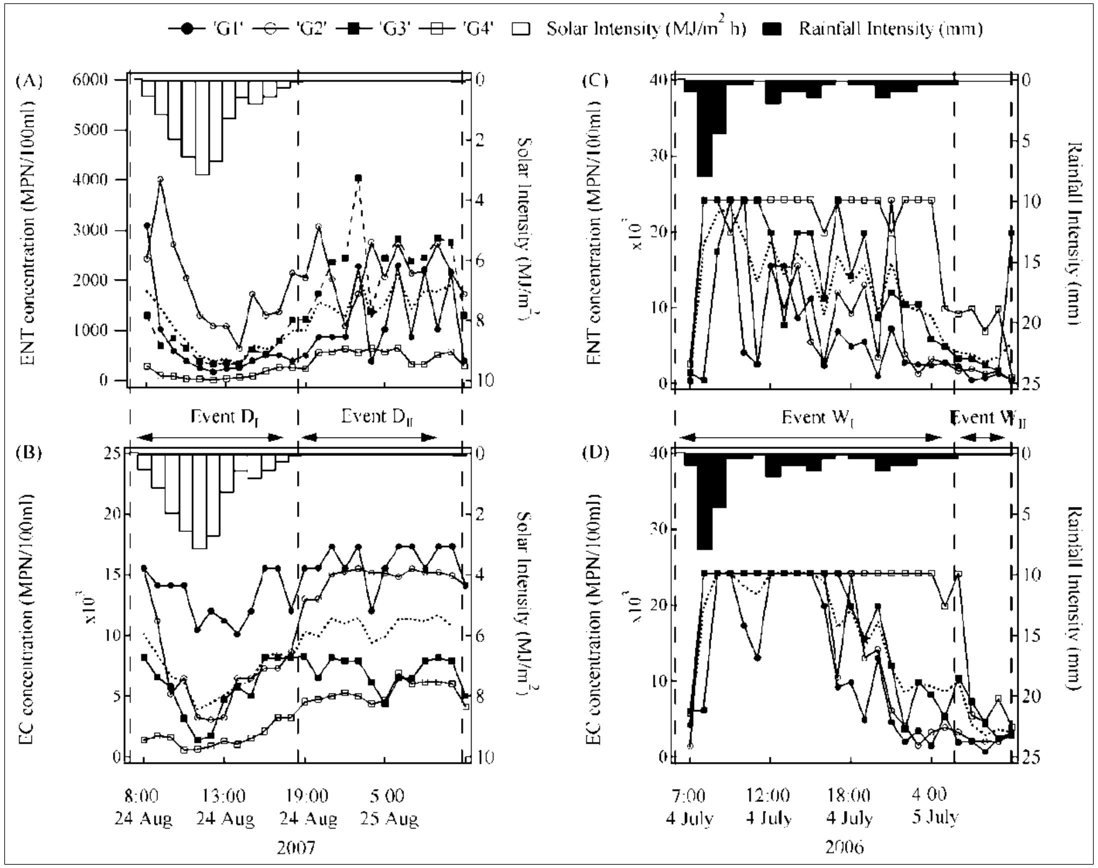
Introduction

- Streambed sediment has been attracting attention as a reservoir for bacteria, including pathogenic strains.
- Soil and Water Assessment Tool (SWAT) has been augmented with a bacteria transport subroutine in SWAT2005 in which bacteria die-off is the only in-stream process
- Limited research has been performed using the SWAT 2005 model for predicting bacteria movement.
- Kim and Pachepsky (2010) modified SWAT module in terms of streambed *E. coli* release and deposition which were computed based on the sediment resuspension and deposition modules.

Modeling Study on the Fate and Transport of Bacteria

Modeling study I- Gwangju Creek

Hourly variations of Fecal Indicator Bacteria (FIB) concentrations



Dry weather condition1 (DW1)

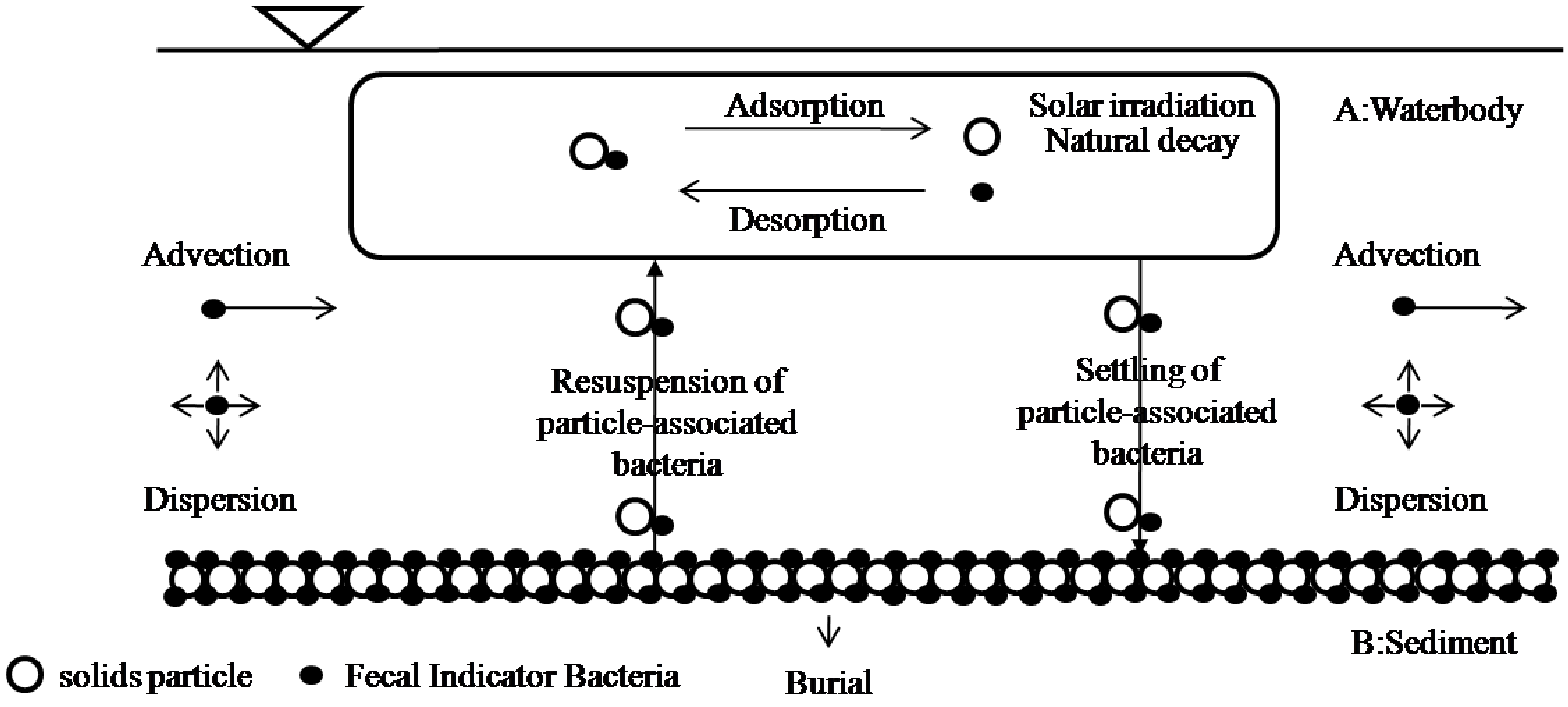
Wet weather condition1 (WW1)

1. EC and ENT concentrations decreased with an increase of solar intensity, increased in the absence of solar intensity.

2. FIB concentration increased at the beginning of a storm, showed a peak with the first peak of rainfall intensity, and then fluctuated in response to the second and third peaks of rainfall intensity.

Cho et al (2010) ,Water Research

Modeling study I-Gwangju Creek

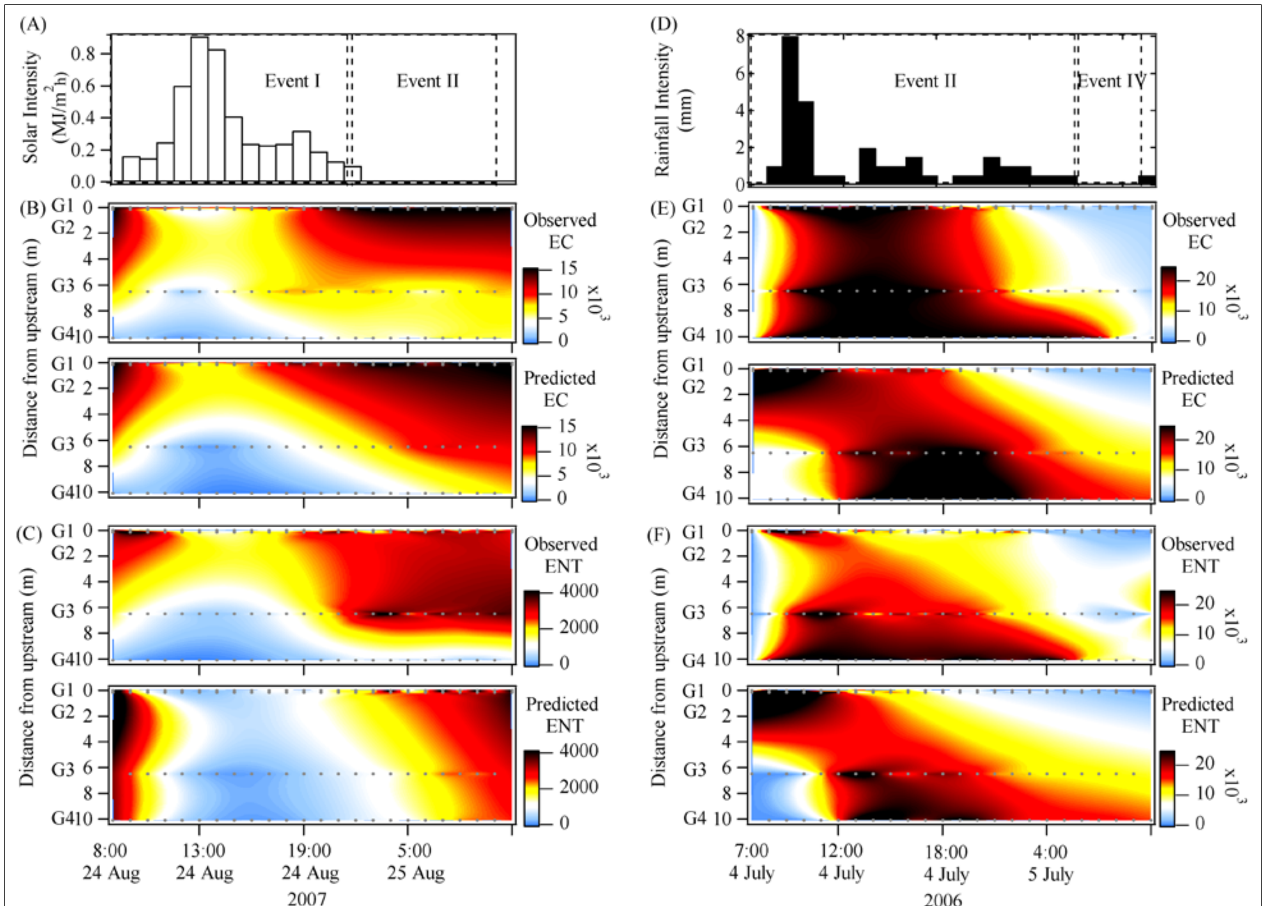


Schematic of key processes incorporated in the FIB model

Cho et al (2010), Water Research

Modeling study I-Gwangju Creek

Color contour plots of the observed and predicted spatiotemporal variations of EC and ENT concentrations



DW1 WW1

Nash-Sutcliffe model efficiency coefficient (NSE)

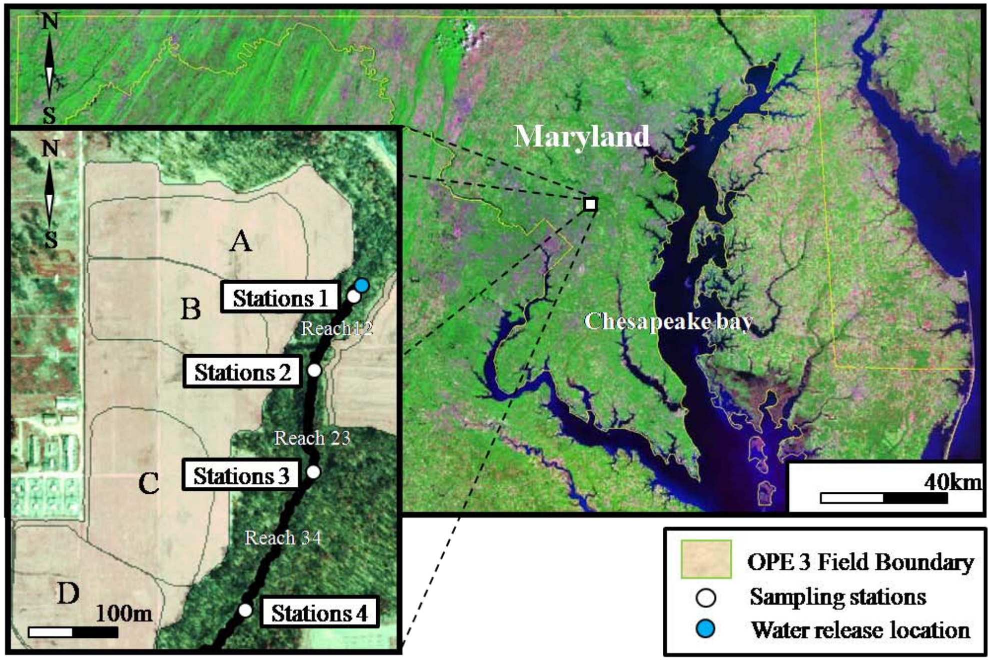
Sites	EC (n=25 [b])		ENT (n=25)	
	Dry	Wet	Dry	Wet
G2	0.70 [a]	-0.02	0.37	0.35
G3	0.62	0.18	0.24	0.14
G4	0.81	0.52	0.54	0.45

1. NSE values in wet weather are lower than those of dry weather for each EC and ENT simulation

2. The relatively poorer FIB prediction in wet weather is probably due to the lack of accurate information for urban runoff and resuspension rates.

Cho et al (2010), Water Research

Modeling study II- OPE3 Creek



Study area at the USDA-ARS the OPE3 research site; (A) Manure applied, (B), (C), and (D): No manure applied.

Water dumping experiment: Quantification of resuspension of *E.coli*

Cho and Pachepsky (In press) Journal of Hydrology

Modeling study II- OPE3 Creek

- **Hydrodynamic model: Saint-Venant equations**

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q$$

groundwater upwelling

continuity equation

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial h}{\partial x}-g(S_o-S_f)=0$$

Moment equation

- **FIB transport model: Advection-Dispersion-Reaction equation**

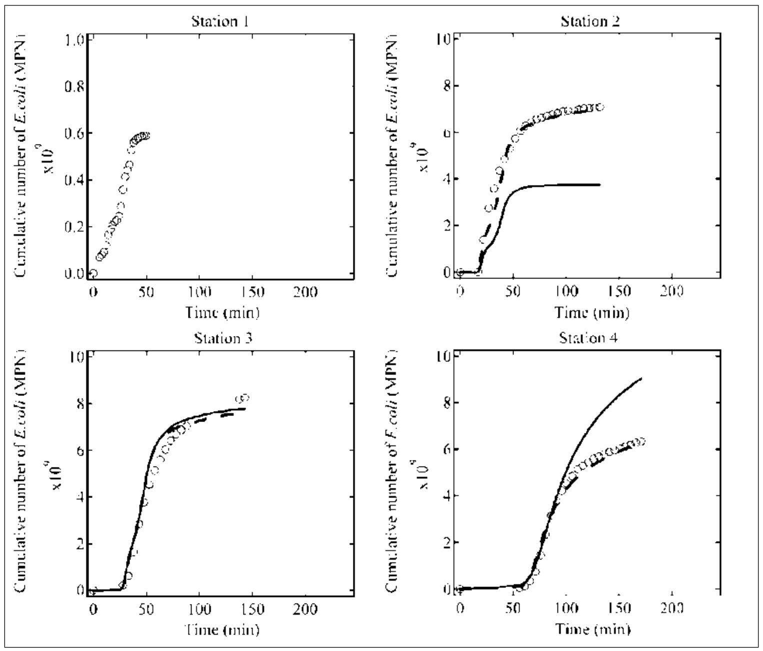
$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}=D\frac{\partial^2 C}{\partial x^2}+R\frac{C_S}{h}-f\frac{v_s}{h}C-\frac{q}{A}C$$

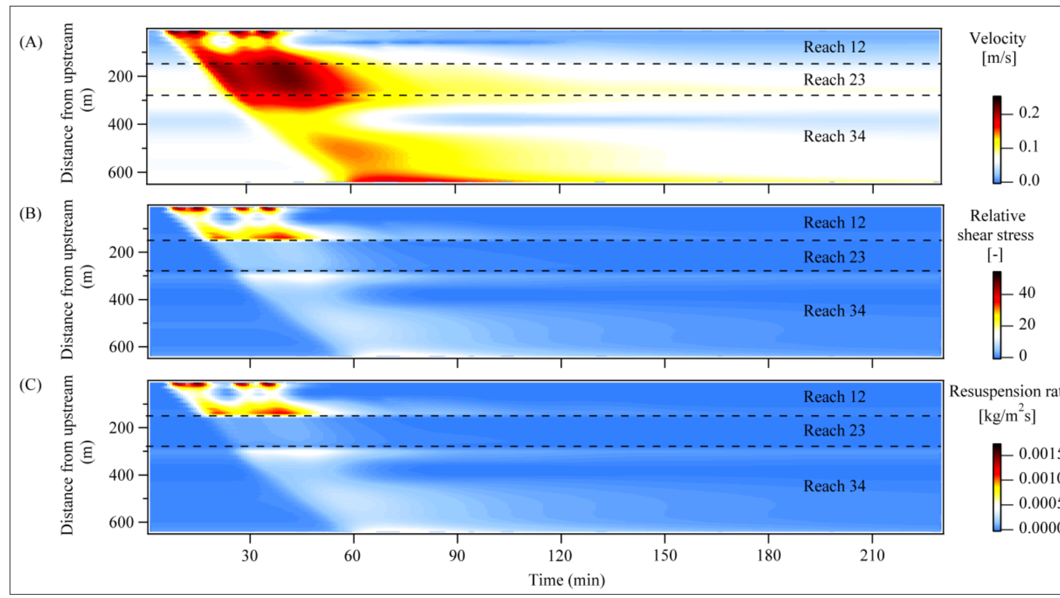
Dilution effect by groundwater upwelling

$$R=\begin{cases} R_e\left(\frac{\tau}{\tau_c}-1\right), & \tau \geq \tau_c \\ 0, & \tau < \tau_c \end{cases}$$

Cho and Pachepsky (In press) Journal of Hydrology

Modeling study II- OPE3 Creek



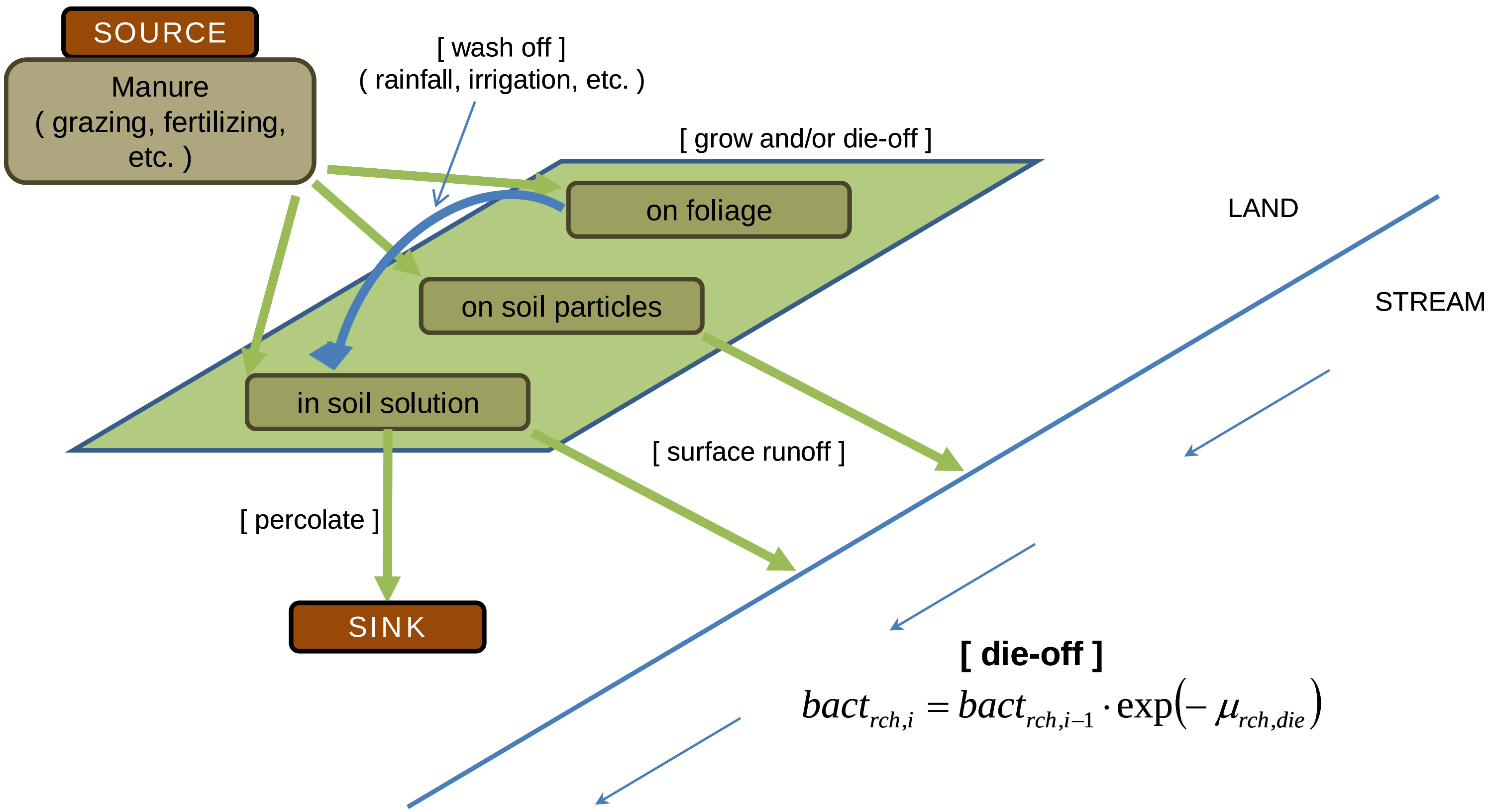


Observed (circles) and simulated (lines) cumulative numbers of *E. coli* cells that have passed monitoring sites during artificial high flow event; solid line – simulated with the same parameters for all reaches, dash line – simulations with reach-specific parameter sets

Spatiotemporal patterns of EC resuspension rate under artificial high flow event; vertical axis is the distance from monitoring site station 1; the color indicates the velocity and *E. coli* resuspension rate ranging from red for the highest and blue for the lowest values.

Cho and Pachepsky (In press) Journal of Hydrology

Bacteria Module in SWAT



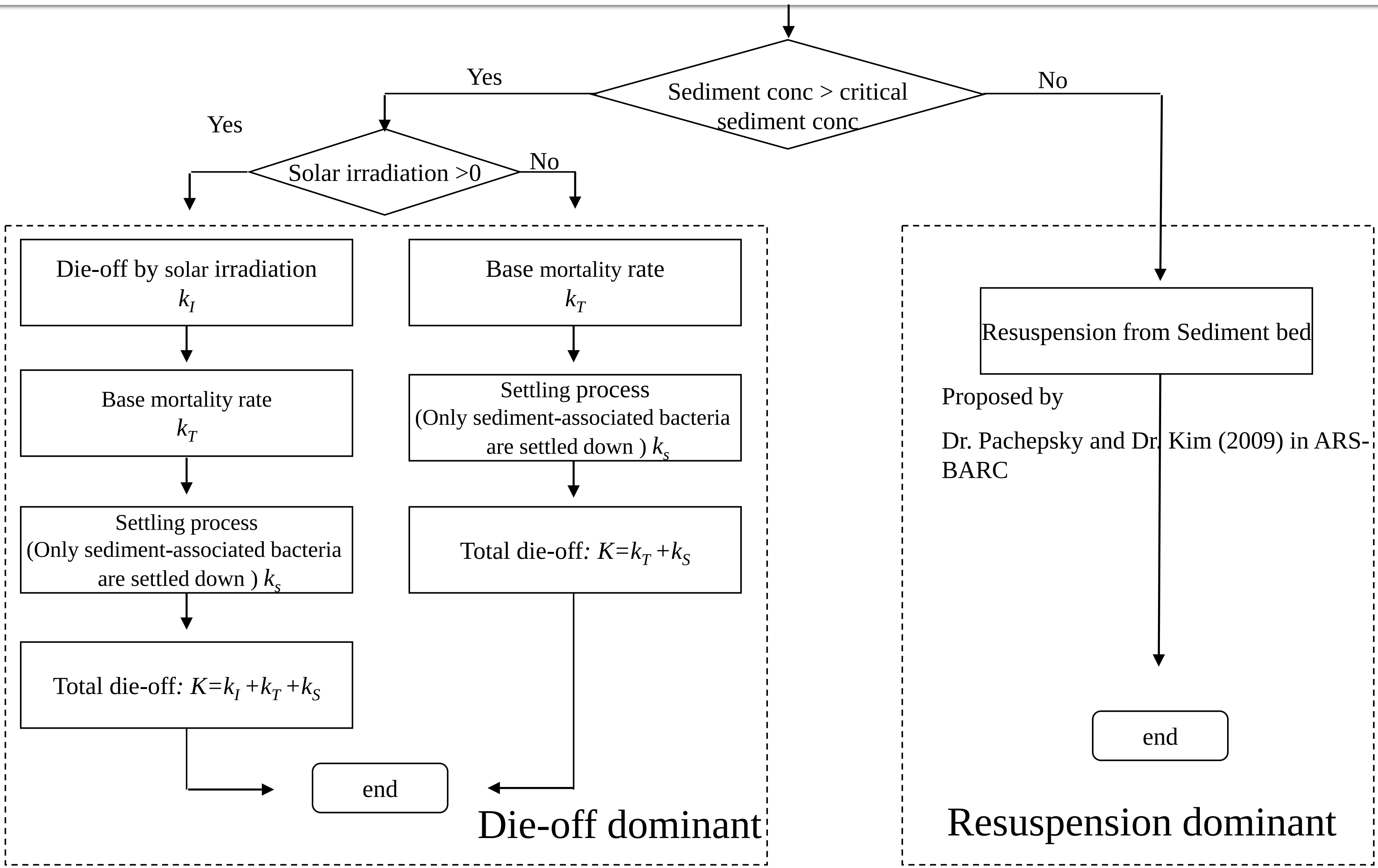
$$bact_{rch,i} = bact_{rch,i-1} \cdot \exp\left(-\mu_{rch,die}\right)$$

Limitations

- The current FIB model in SWAT is <u>oversimplified</u> to predict FIB in waterbody.
- The <u>solar intensity and resuspension</u> did not apply to compute the fate of FIB in water column.

Modeling Approach

Modeling Approach



Modeling Approach

Bacteria module in SWAT (Kim and Pachepsky, 2010, Ecological Modelling)

$$M_{B,res} = M_{s,res} \cdot C_{B,B}$$

$M_{B,res}$=*E. coli* (CFU)
$M_{S,res}$=the mass of resuspended sediment (ton)
$C_{B,B}$=the E. coli concentration in streambed sediments

$$\frac{M_{B,free} + M_{B,sus} + M_{B,dep}}{M_{B,W}} = \frac{1 + K_P \cdot conc_{sed,sus} + K_P \cdot conc_{sed,dep}}{1 + K_P \cdot conc_{sed,i}}$$

$M_{B,W}$= the *E. coli* suspended in stream water
$conc_{sed,i}$= the concentration of suspended sediments
$conc_{sed,dep}$= the concentration of deposited sediments
K_p =the partitioning coefficient

$$M_{B,dep} = M_{B,W} \cdot \frac{K_P \cdot M_{S,dep}}{Q + K_P \cdot M_{S,W}}$$

$M_{B,W}$= the number of *E. coli* deposited

$$\log K_p = (-1.6 \pm 0.9) + (1.98 \pm 0.7) \cdot \log CL$$

CL=the percentage of clay in sediment

Modeling Approach

New Bacteria module in SWAT

$$k_t = k_n + k_s \square I(t)$$

$k_{t,}$ = *total die-off rate*
k_n = *natural die-off rate*
k_s= *solar intensity coefficient*
I(t)= *daily averaged solar intensity*

$$k_t = k_t \cdot \theta^{T-20}$$

T= *Water temperature*

θ = *Temperature adjustment factor*

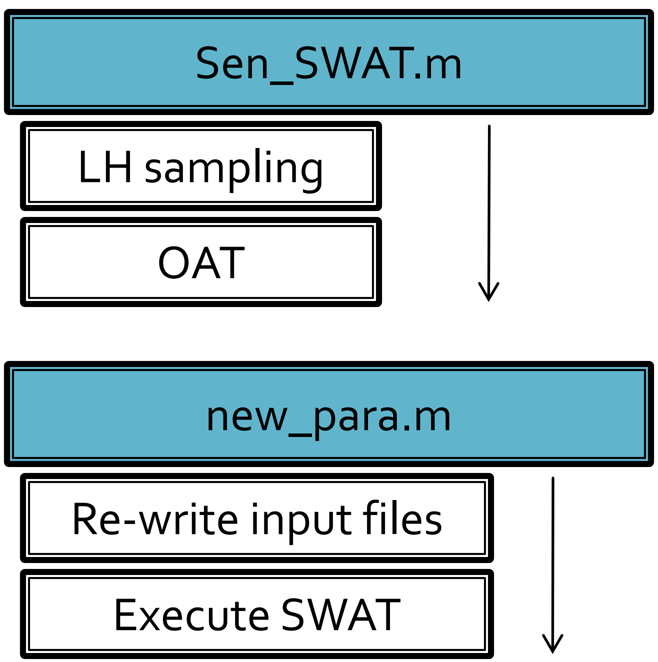
$$bact_{rch,j} = bact_{rch,j-1} \cdot \exp(-k_t)$$

$Bact_{rch,j\text{-}1}$ = *bacteria concentration in j-1 day*
$Bact_{rch,j}$ = *bacteria concentration in j day*

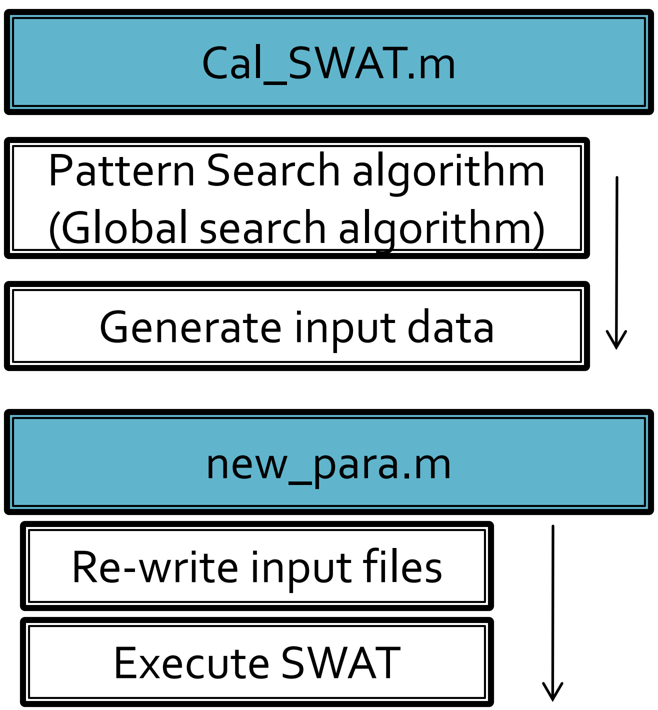
Modeling Approach

Sensitivity analysis and auto-calibration (MATLAB)

Sensitivity analysis

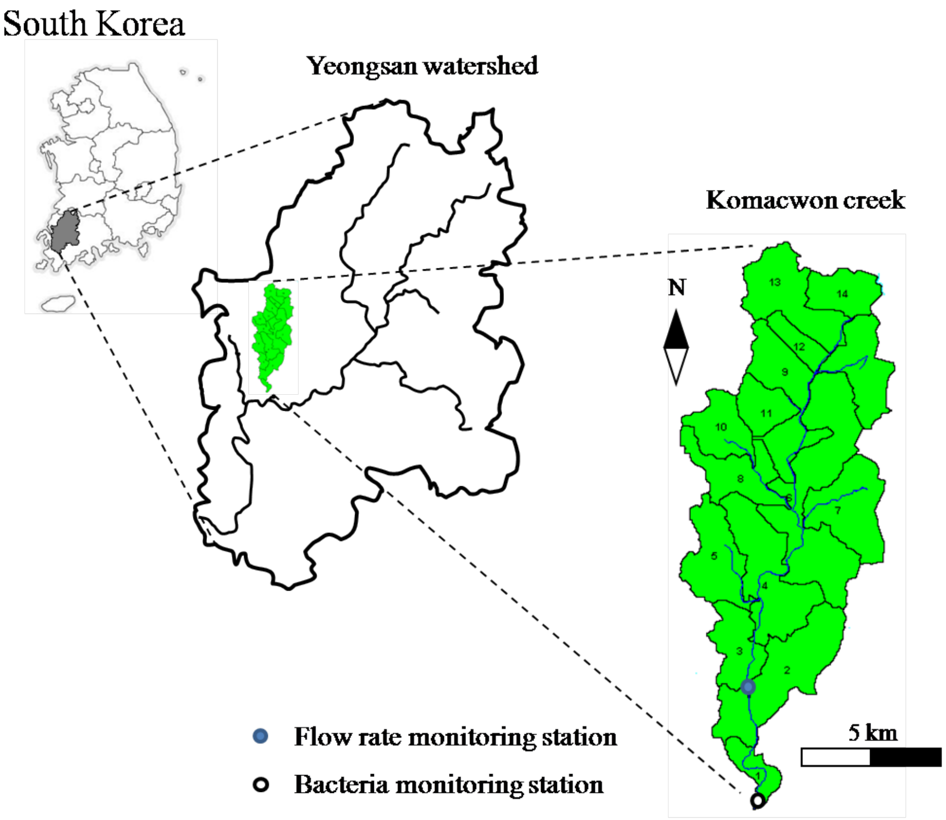


auto-calibration



Modeling Results

Study area: Komacwon Creek



Study area-the Komacwon Creek (KMC) catchment

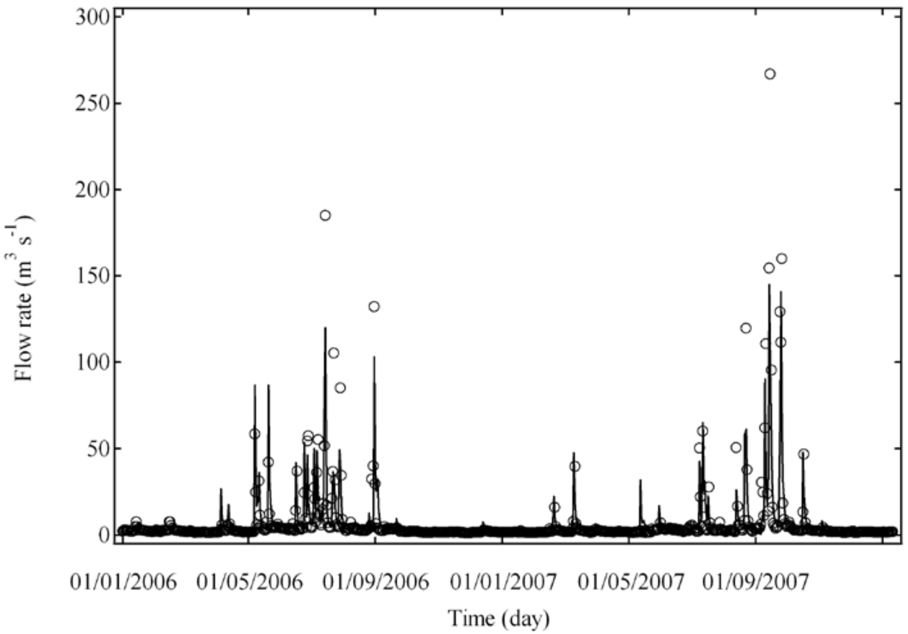
Description of the Komacwon Creek (KMC) catchment

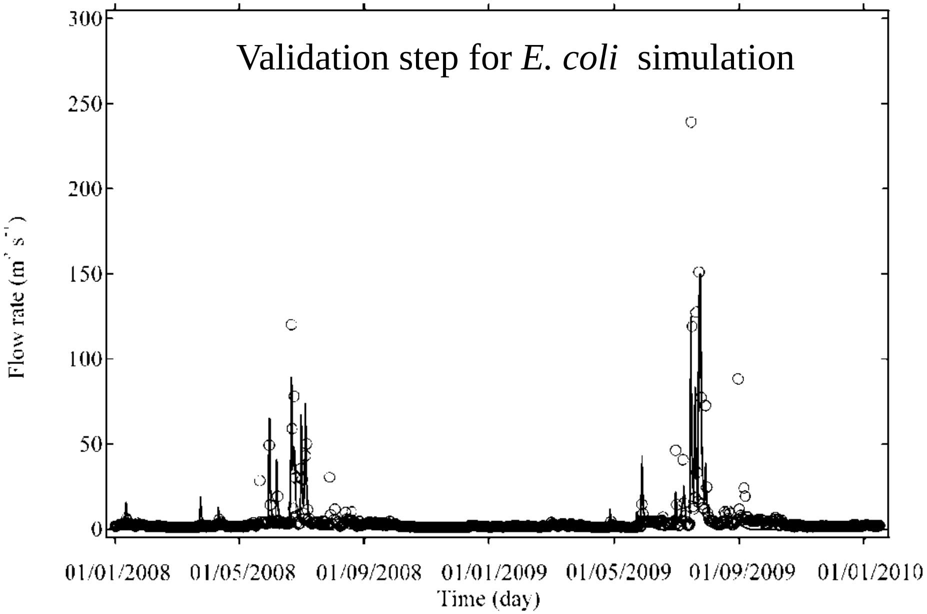
Komacwon Creek catchment characteristics	unit	value
Total length	km	36
Watershed area	km^2	217.05
Forest-Evergreen	ha	7258.76
Rice	ha	5977.06
Soybean	ha	3463.23
Forest-Mixed	ha	1283.54
Residential-High Density	ha	640

Modeling Results-sensitivity analysis (hydrologic module)

Parameter	Min	Max	Rank	S	Value	Definition	process
CN2	-70	50	1	7.70E-01	70.18	Initial SCS runoff curve number for moisture condition II	Runoff
CH_K2	0	150	2	2.84E-01	150	[CH_K(2)] Effective hydraulic conductivity in main channel alluvium (mm/hr)	Channel
SURLAG	0	10	3	2.48E-01	0.28	Surface runoff lag coefficient	Runoff
ALPHA_BF	0	1	4	2.11E-01	0.93	Baseflow alpha factor-Baseflow recession constant	Groundwater
SOL_Z	-50	50	5	1.03E-01		Depth from soil surface to bottom of layer (mm)	Soil
CH_N	-20	20	6	8.03E-02	0.10	Manning's "n" value	Channel
ESCO	0	1	7	7.98E-02	0.00	Soil evaporation compensation factor	Evaporation
SOL_AWC	-50	50	8	5.04E-02		Available water capacity of the soil layer (mm H2O/mm soil)	Soil
SLSUBBSN	-50	50	9	2.45E-02		Average slope length (m)	Geomorphology
CANMX	0	15	10	2.19E-02		Maximum canopy storage (mm H2O)	Runoff
SLOPE	-50	50	11	2.10E-02		[HRU_SLP] Average slope steepness (m/m)	Geomorphology
SOL_K	-50	50	12	1.98E-02		Saturated hydraulic conductivity (mm/hr)	Soil
GWQMN	0	5000	13	6.21E-03		Threshold depth of water in the shallow aquifer for return flow (mm H2O)	Soil
EPCO	-50	50	14	5.36E-03		Plant uptake compensation factor	Evaporation
TIMP	0.01	1	15	5.35E-03		Snow pack temperature lag factor	Snow
BIOMIX	0	1	16	4.13E-03		Biological mixing efficiency	Soil
SMFMX	0	10	17	2.04E-03		Melt factor for snow on June 21 (mm H2O/°C-day)	Snow
RCHRG_DP	0	1	18	1.91E-03		Deep aquifer percolation fraction	Groundwater
SMTMP	0	5	19	1.63E-03		Snow melt base temperature (°C)	Snow
SFTMP	0	5	20	1.43E-03		Snowfall temperature (°C)	Snow
GW_DELAY	0	100	21	5.55E-04		Groundwater delay time (days)	Groundwater
SOL_ALB	0	1	22	4.92E-04		Moist soil albedo	Evaporation
SMFMN	0	10	23	9.16E-05		Melt factor for snow on December 21(mm H2O/°C-day)	Snow
GW_REVAP	0.02	0.2	24	6.97E-05		Groundwater "revap" coefficient	Groundwater
REVAPMN	0	500	28	0.00E+00		Threshold depth of water in the shallow aquifer for percolation to the deep aquifer (mm H2O)	Groundwater
TLAPS	-50	50	28	0.00E+00		Temperature lapse rate (°C/km)	Geomorphology
BLAI	-50	50	28	0.00E+00		Maximum potential leaf area index	Crop

Modeling Results-flow rates





Root-mean-squared error (RMSE) and Nash-Sutcliffe model efficiency (NSE) coefficient `

RMSE $[m^3 s^{-1}]$	NSE [-]
4.16	0.89

RMSE $[m^3 s^{-1}]$	NSE [-]
4.04	0.85

Modeling Results-Sensitivity analysis (without resuspension)

Sensitive parameters among 24 parameters for E. coli simulation

	Parameter	Min	Max	Definition
Rank 1	NATDIEP	0	1	Natural die-off rate [1/s]
Rank 2	WDPRCH	0	1	Solar intensity coefficient [$m^{2/}$MJ/day]
Rank 3	FILTERW	0	2	Width of edge-of-field filter strip (m)
Rank 4	PHU_PLT	1000	2000	Total number of heat units or growing degree days needed to bring plant to maturity (days)
Rank 5	USLE_P	0.1	1.0	USLE equation support practice factor
Rank 6	LAI_INIT	0	1	Initial leaf area index
Rank 7	Bio_TRMP	10	100	Dry weight of biomass trampled daily (kg/day/ha)

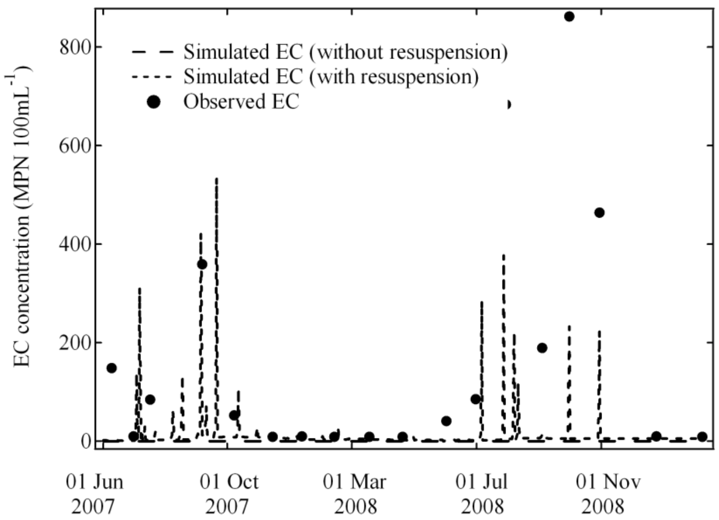
Modeling Results-Sensitivity analysis (with resuspension)

Sensitive parameters among 24 parameters for E. coli simulation

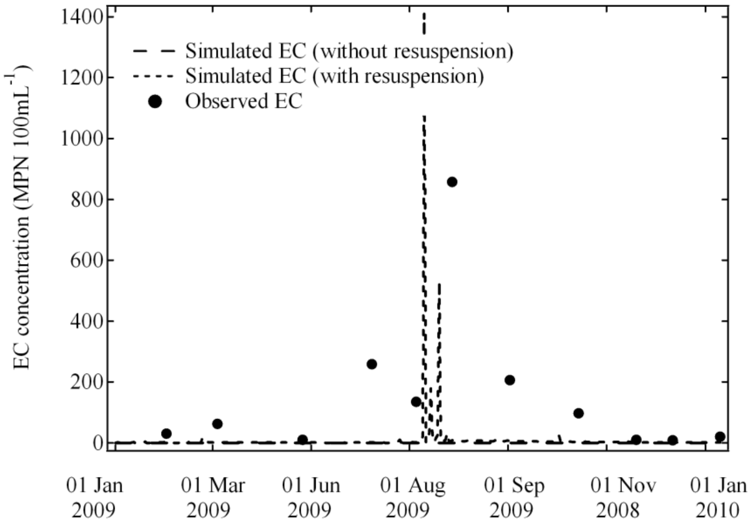
	Parameter	Min	Max	Definition
Rank 1	PRF	0	1	Peak rate adjustment factor for calculating the channel sediment routing
Rank 2	ADJ_PKR	0	1	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)
Rank 3	NATDIEP	0	1	Natural die-off rate [1/s]
Rank 4	SPCON	0.0001	0.01	Linear parameter for calculating the channel sediment routing
Rank 5	SPEXP	1.0	1.5	Exponent parameter for calculating the channel sediment routing
Rank 6	WDPRCH	0	1	Solar intensity coefficient [$m^{2/}$MJ/day]
Rank 7	CH_EROD	0	1	Channel erodibility factor
Rank 8	CH_COV	0	1	Channel cover factor

Modeling Results – *E. coli* simulation

Calibration step for *E. coli* simulation



Validation step for *E. coli* simulation



Root-mean-squared error (RMSE) and Nash-Sutcliffe model efficiency (NSE) coefficient

		E. coli	
		$RMSE \cdot 10^2$ [MPN]	NSE [-]
Original	Calibration	3.01	-0.46
	Validation	2.82	-0.43
Modified	Calibration	2.97	0.13
	Validation	2.79	0.39

1. Insufficient information on wildlife
2. The amount of Manure application
3. The uncertainty in estimation of sediment EC concentration

Conclusion

- Overall, the SWAT model modified with the streambed *E. coli* release and deposition and solar intensity modules showed better performance in predicting *E. coli* concentration in stream water as compared to the original SWAT model.

- Although the an error in the performance of the modified SWAT model found, this study demonstrate the significance of EC release from streambed and deposition die-off by solar intensity for the SWAT microbial module.

Future works

- Uncertainty of parameters associated with streambed
- Shear stress concept for resuspension
- Hourly and sub-hourly simulation for *E. coli*
- Coupling with bacteria module in CE-QUAL-W2
- Bacteria-associated BMP

Thank you