Developing new bacteria subroutines in the SWAT model

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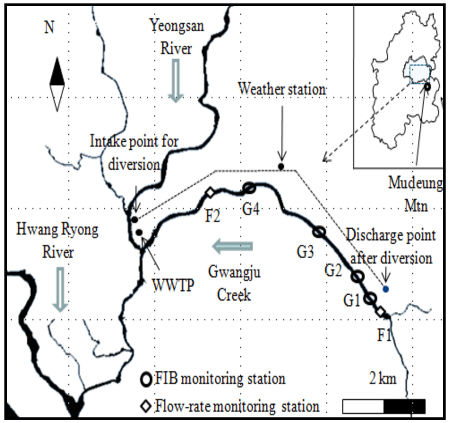
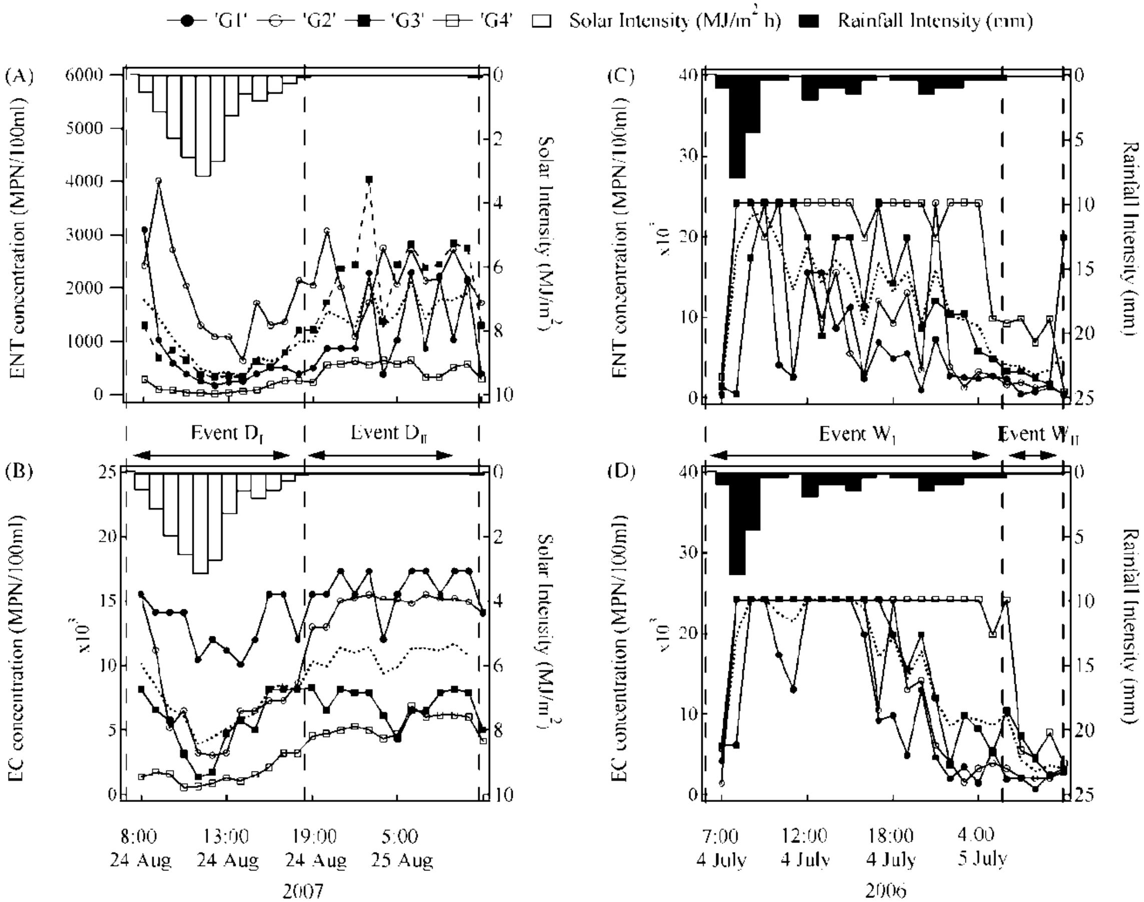
Monitoring 1 (River/hourly scale)



Gwangju, South Korea

Cho et al (2010), Water Research



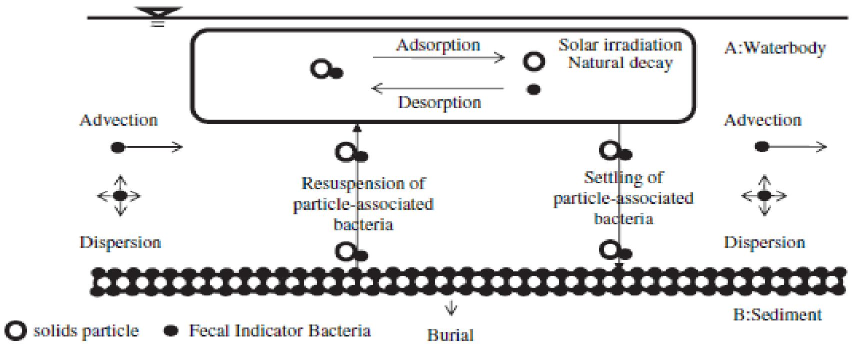
Dry weather condition1

Wet weather condition

Monitoring results

Modeling 1 (River/hourly scale)

Method



Schematic of key processes incorporated in the bacteria model

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

Mass balance

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0$$

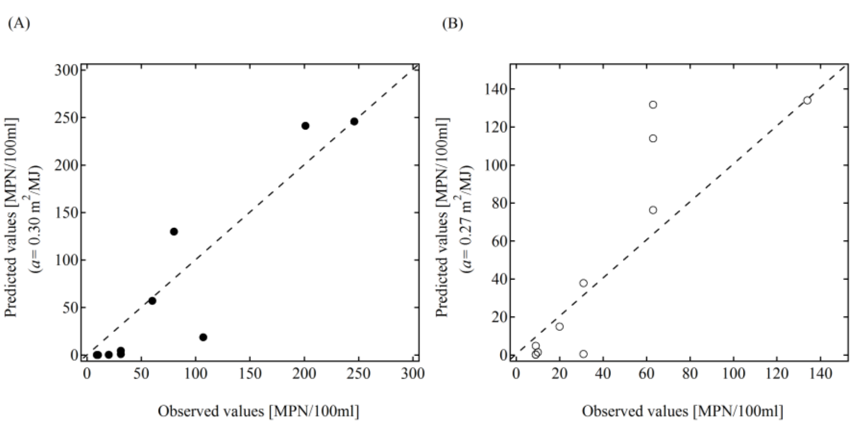
Momentum balance

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

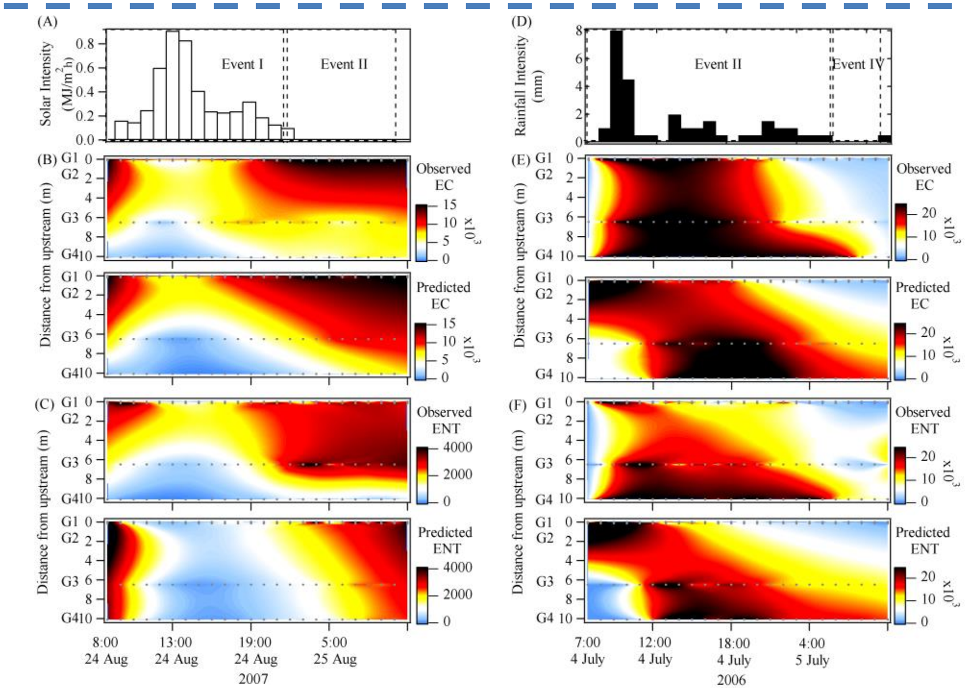
* **Transport model: Advection-Dispersion-Reaction-Resuspenstion**

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}-D\frac{\partial^2 C}{\partial x^2}+kC-R\frac{C_s}{h}=source\ term$$

Results



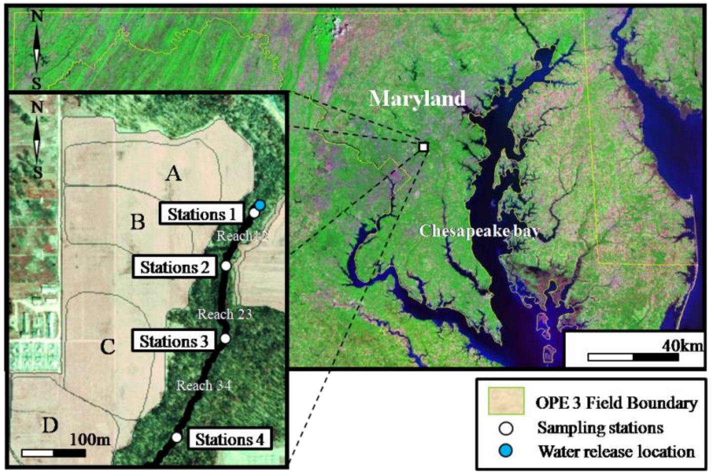
By chamber experiment, the values of α for ENT and EC were determined to be 0.27 m2 MJ-1 and 0.30 m2 MJ-1



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

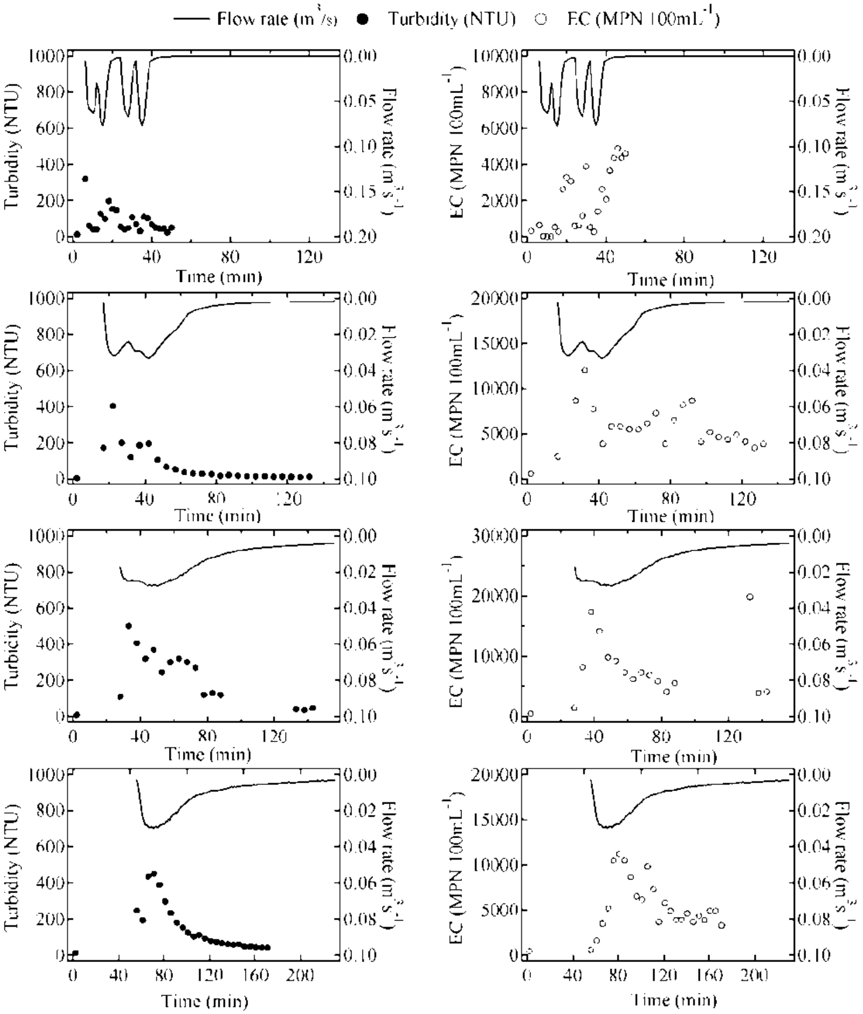
Cho et al (2010), Water Research

Monitoring 2 (Creek/sub-hourly scale)



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

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



Flow rates, turbidity, and EC concentrations during an artificial high-flow event

Cho et al (2010), Journal of Hydrology

Modeling 2 (Creek/sub-hourly scale)

* **Hydrodynamic model: Saint-Venant equation**

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

groundwater upwelling

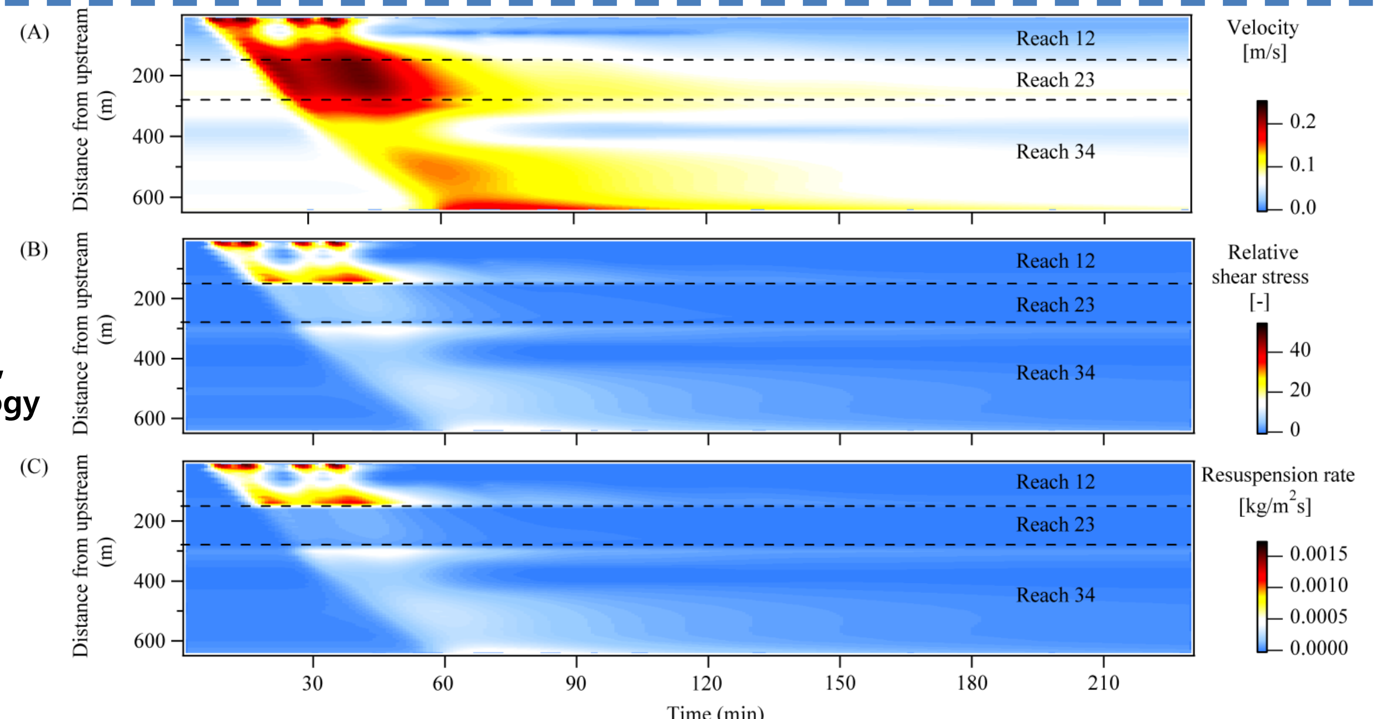
$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial h}{\partial x}-g(S_o-S_f)=0$$

* **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

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



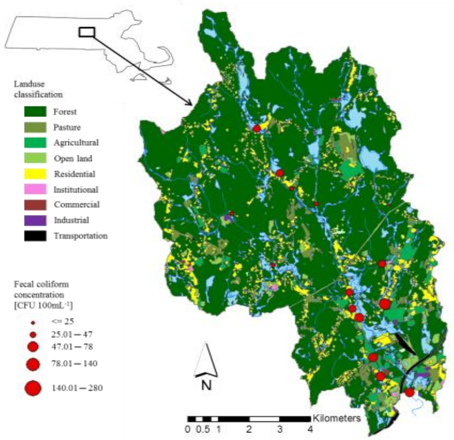
Cho et al (2010), Journal of Hydrology

Spatiotemporal patterns of calculated velocity (A), relative shear stress (B), and *E. coli* resuspension rate (C) under artificial high flow event; vertical axis is the distance from monitoring site station

Bacteria module in SWAT

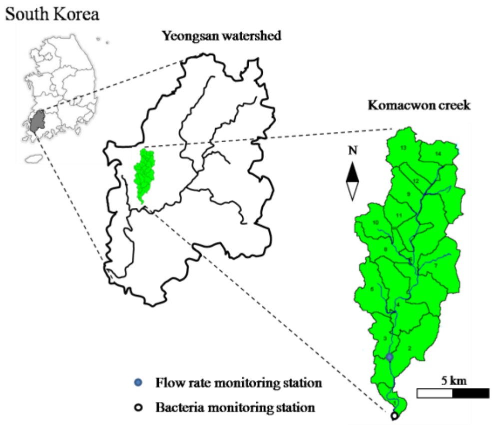
- The Soil and Water Assessment Tool (SWAT) was expanded by adding a bacteria module (Sadeghi and Arnold, 2002).
- Baffaut and Benson (2003) used the bacteria module to predict flow rates and fecal coliform concentration.
- Parajuli et al., (2007; 2009) applied this module to modeling nutrient and fecal coliform in two different sub-basins in Kansas.
- Coffey et al. (2010) used the original version of the SWAT to predict fecal coliform in Irish catchments, showing satisfactory prediction accuracies in the calibration step.
- In addition, the SWAT bacteria module was modified to consider streambed fecal coliform release and deposition (Kim et al., 2010).
- The effect of solar radiation has been considered in simulations of fecal coliform concentration in a water body (Cho et al., 2012).

Study sites



Stillwater, MA

Prof. Tobiason



Komacwon, Korea

Prof. Joon Ha Kim

Fig. 1. Little Cove Creek watershed in southern Pennsylvania and the location of three stream monitoring sites (CM2, CM3, and CM7) and three rainfall stations (TB2, TB3, and TB7).

Little cove, PA

Dr. Yakov Pachepsky

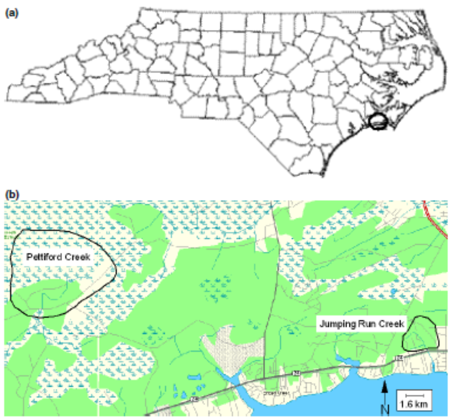


FIGURE 1. Locations of Pettiford and Jumping Run Creeks Watersheds.

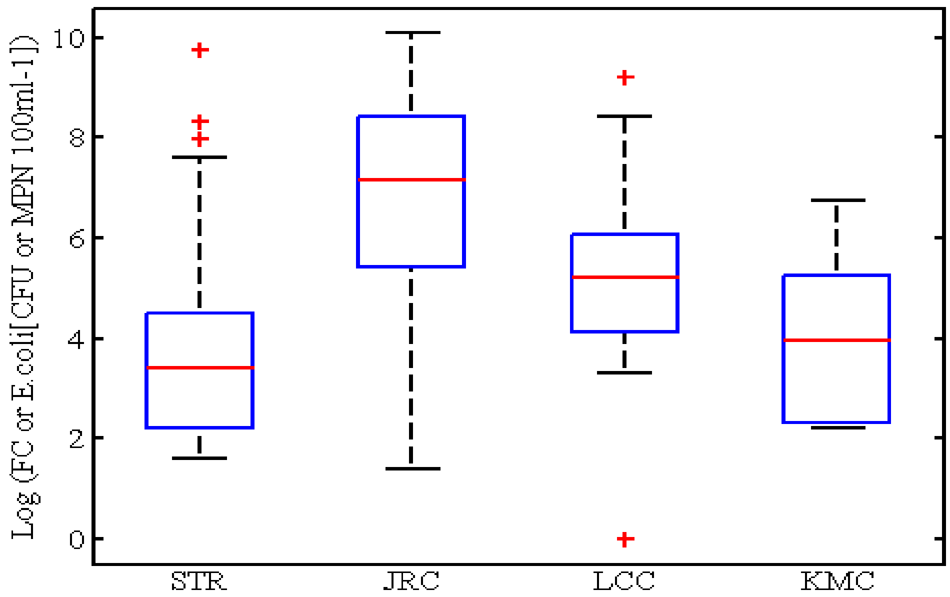
Jumping run, NC

Dr. Drew Gronewold

Land use

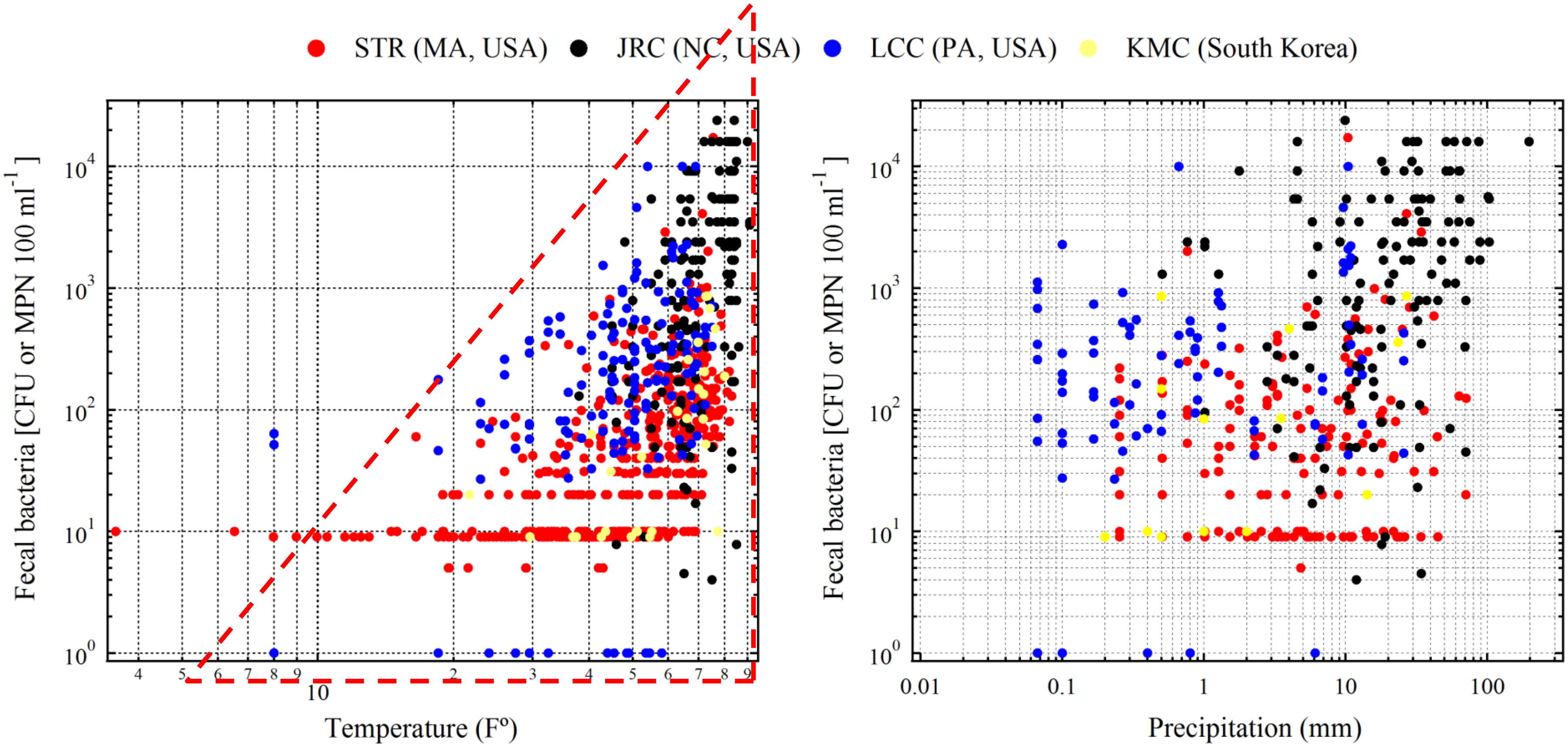
	Komacwon Creek	Jumping Run Creek	Little Cove Creek	Stillwater River
Watershed area [km^2]	40.7	3.2	68.0	76.9
Agriculture [%]	43.68	-	-	3.5
Pasture [%]	-	-	25.0	2.7
Forest [%]	43.09	51.95	71.9	73.6
Residential [%]	3.13	49.05	-	7.5

Box plots on bacterial observation



``	Stillwater River	Jumping Run Creek	Little Cove Creek	Komacwon Creek
Sampling period	2005-2009	1998-2004	2008	2007-2009
# of Samples	462	85	52	29

Dominant factor: Regrowth vs Runoff?



Bacterial sources

	Sources	Sites	Landuse
Livestock	Cattle	LCC, STR	Pasture
	Horses		
	Swine		
Wildlife	Deer	JRC, LCC, ST R	Forest, Water
	Ducks		
	Geese		
	Beaver		
Residential	Falling septic	KMC, JRC, S TR	Residential area
Agricultural source	Manure	KMC, LCC, S TR	Agriculture

Original version of SWAT

Die-off Growth

Foliage

$$bact_{lpfol,i} = bact_{lpfol,i-1} \cdot \exp\left(-\boxed{\mu_{lpfol,net}}\right) - bact_{\min,lp} \qquad \mu_{lpfol,net} = \boxed{\mu_{lpfol,net,20}} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{lpfol,net,20} = \mu_{lpfol,die,20} - \mu_{lpfol,grw,20}$$

$$bact_{pfol,i} = bact_{pfol,i-1} \cdot \exp\left(-\mu_{pfol,net}\right) - bact_{\min,p} \qquad \mu_{pfol,net} = \mu_{pfol,net,20} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{pfol,net,20} = \mu_{pfol,die,20} - \mu_{pfol,grw,20}$$

Soil solution

$$bact_{lpsol,i} = bact_{lpsol,i-1} \cdot \exp\left(-\mu_{lpsol,net}\right) - bact_{\min,lp} \qquad \mu_{lpsol,net} = \mu_{lpsol,net,20} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{lpsol,net,20} = \mu_{lpsol,die,20} - \mu_{lpsol,grw,20}$$

$$bact_{psol,i} = bact_{psol,i-1} \cdot \exp\left(-\mu_{psol,net}\right) - bact_{\min,p} \qquad \mu_{psol,net} = \mu_{psol,net,20} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{psol,net,20} = \mu_{psol,die,20} - \mu_{psol,grw,20}$$

Sorbed in soil

$$bact_{lpsorb,i} = bact_{lpsorb,i-1} \cdot \exp\left(-\mu_{lpsorb,net}\right) - bact_{\min,lp} \qquad \mu_{lpsorb,net} = \mu_{lpsorb,net,20} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{lpsorb,net,20} = \mu_{lpsorb,die,20} - \mu_{lpsorb,grw,20}$$

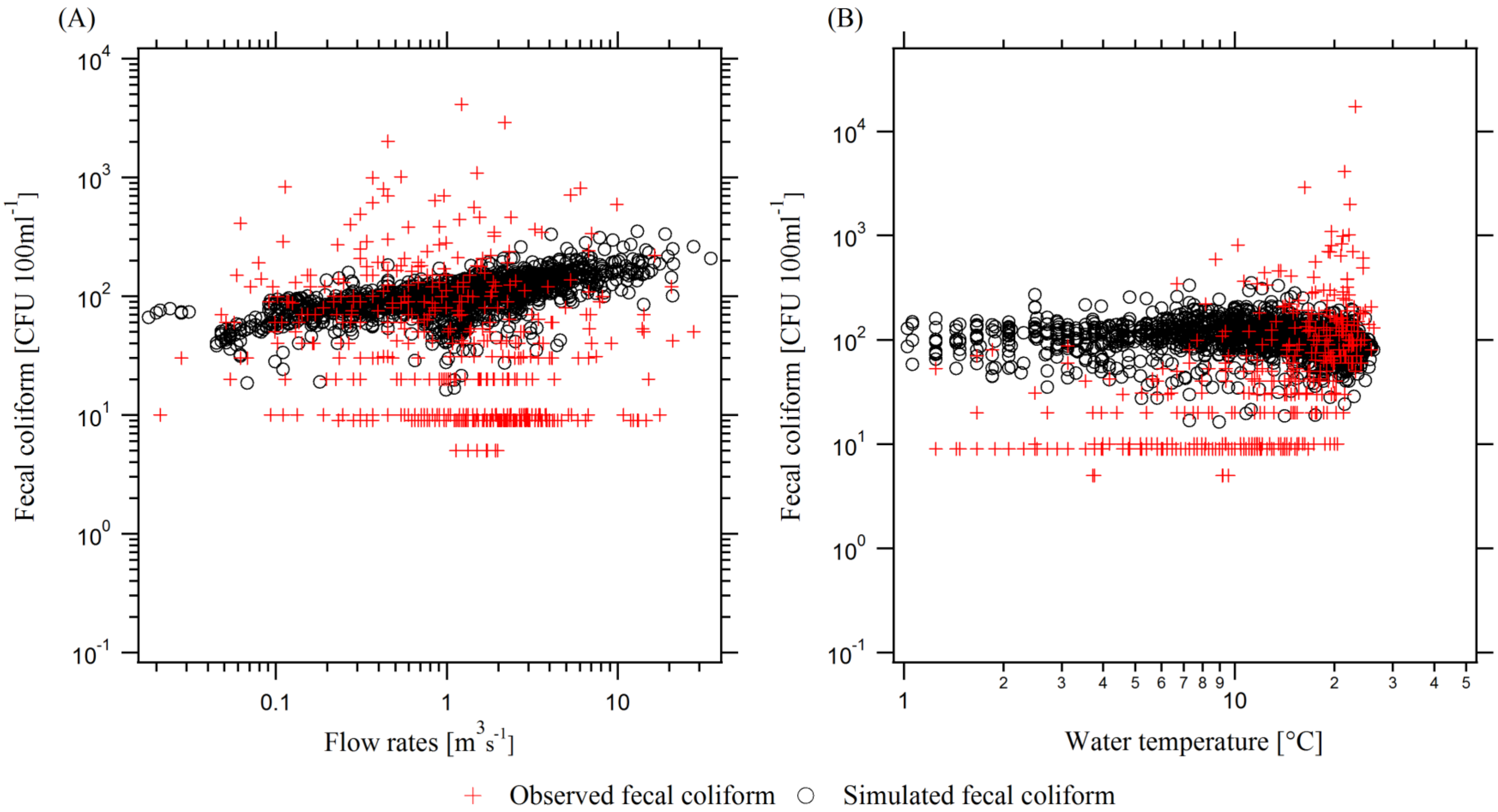
$$bact_{psorb,i} = bact_{psorb,i-1} \cdot \exp\left(-\mu_{psorb,net}\right) - bact_{\min,p} \qquad \mu_{psorb,net} = \mu_{psorb,net,20} \cdot \theta_{bact}^{(\bar{T}_{av}-20)} \qquad \mu_{psorb,net,20} = \mu_{psorb,die,20} - \mu_{psorb,grw,20}$$

Limitation:
It does not have any consideration on the seasonal variability of regrowth/die-off

For example,
If dieoff rate is 0.2 and growth is 0.1, bacteria are always going to be died during the simulation.

If growth rate is 0.2 and dieoff is 0.1, bacteria are always going to be grown during the simulation.

Dominant factor: Regrowth vs Runoff?



Modeling with the original version of SWAT

Cho et al (2012), Water Research

New bacterial subroutines I

Original version of SWAT

Bacteria sources

Soil bacteria module

First-order decay/re-growth

In-stream bacteria module

First-order decay

Modified version of SWAT

Bacteria sources

Air Temperature > Critical Temperature

No

First-order decay

Yes

Re-growth

Sediment conc. > Critical sediment conc.

No

Resuspension dominant

Yes

Die-off by sunlight

+

Removal by settling

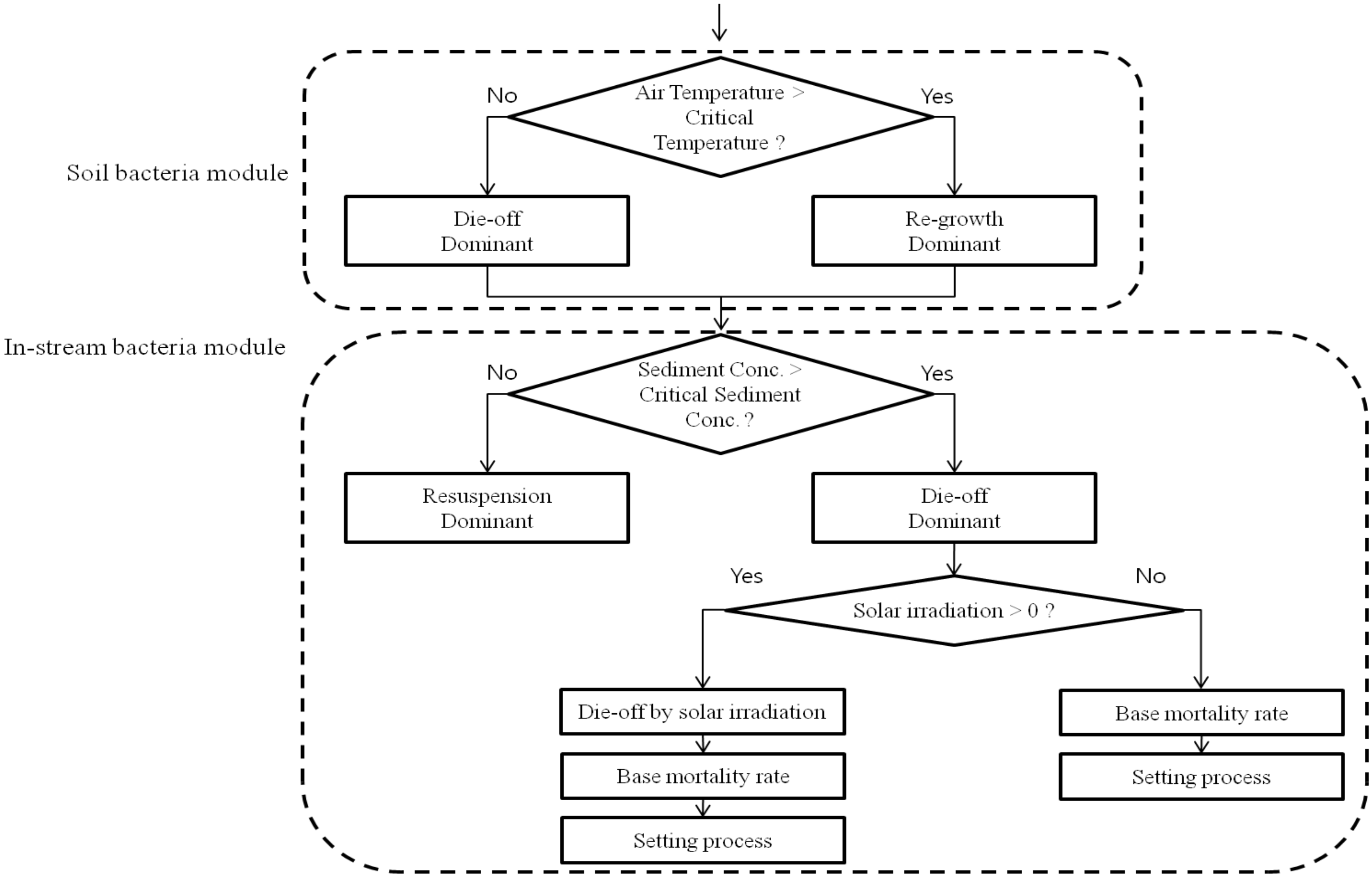
+

Natural decay

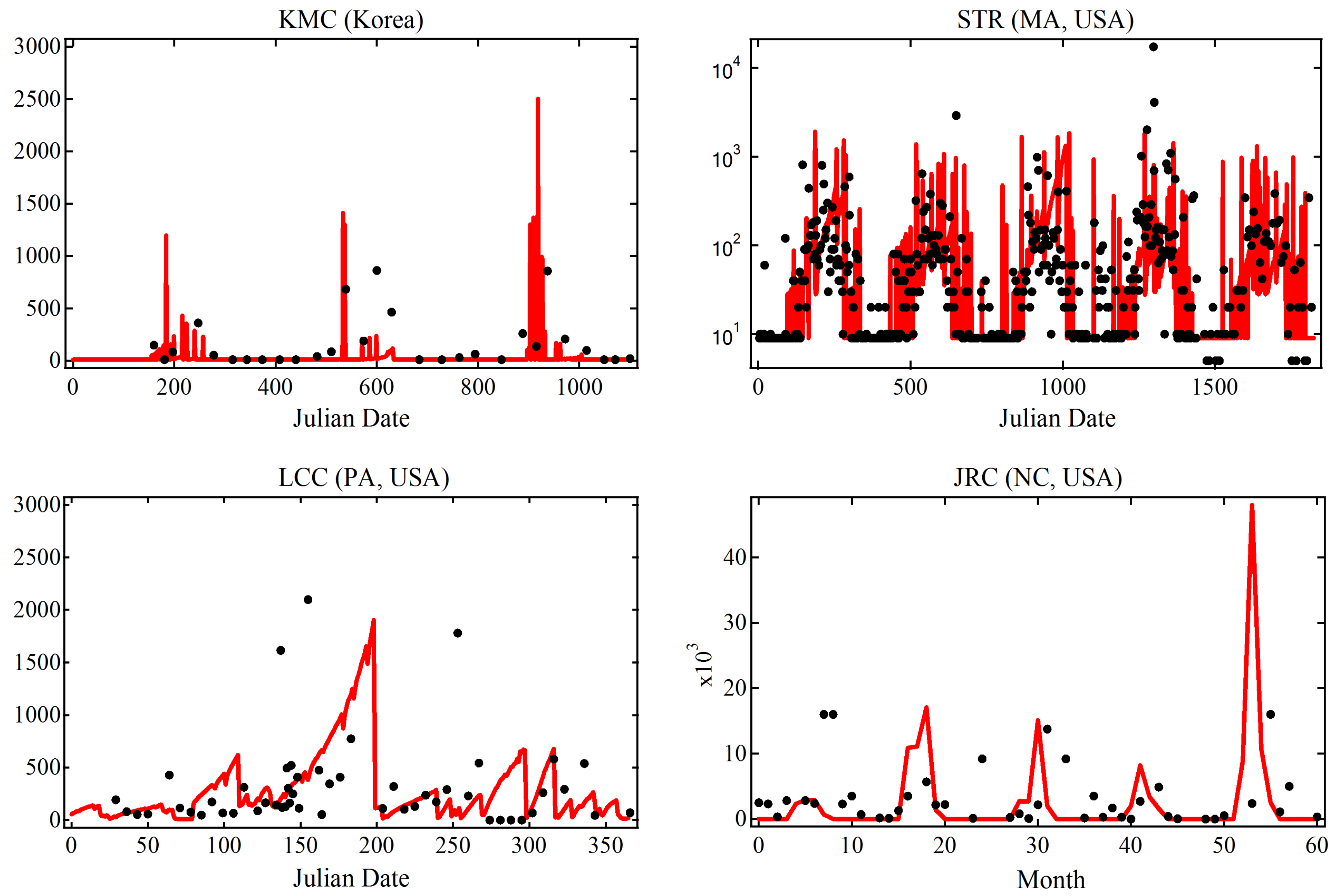
=

Total Die-off

New bacterial subroutines II



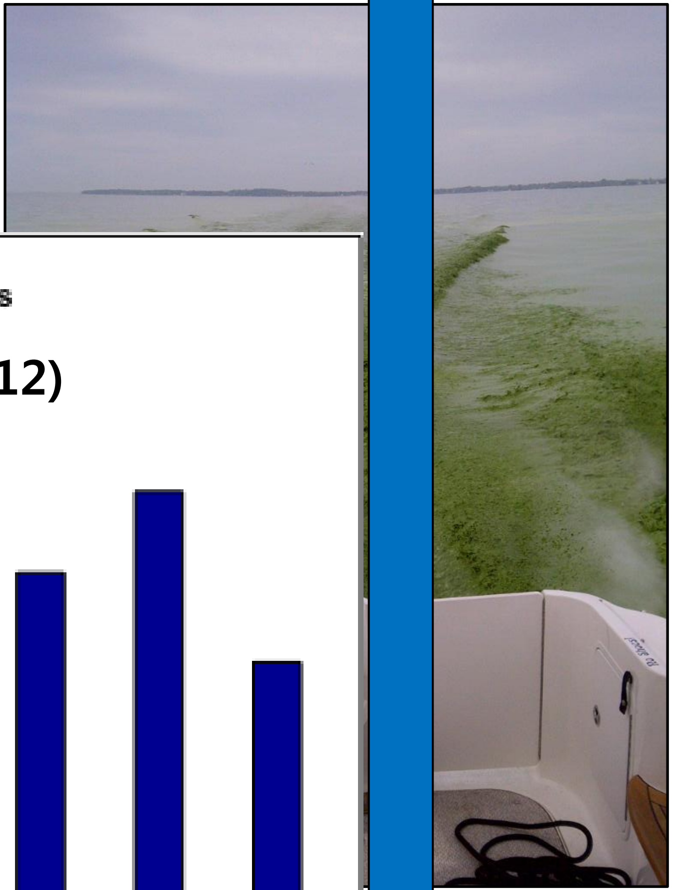
Modeling results

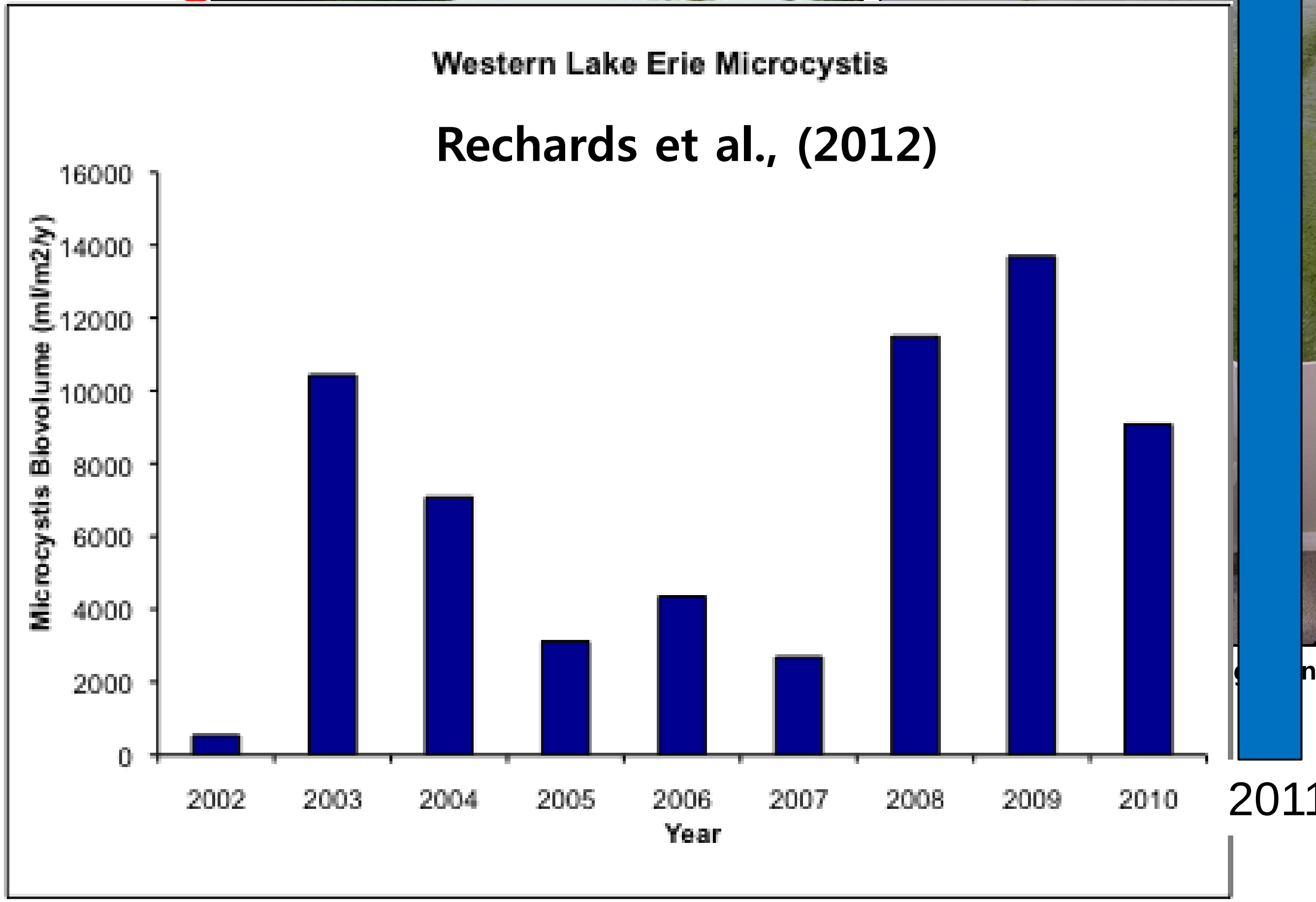


Conclusion

- We found seasonal variability of bacteria concentrations in four watersheds, showing that high concentrations in summer and low concentration in winter.
- It can be explained by that bacterial regrowth is dominant in summer season, while bacteria are inactivated or died in winter season in both soil and surface waters.
- SWAT model is oversimplified to simulate the seasonal variability of bacteria; thereby it was modified by adding new subroutine, attempting to simulate bacterial regrowth and die-off in both soil and in-stream.
- The modified SWAT model well reproduced the seasonal variability of fecal bacteria from four different watersheds.
- The modified SWAT module was validated with bacteria observation could be a reliable assessment tool which provides scientific information for water quality and public health management.

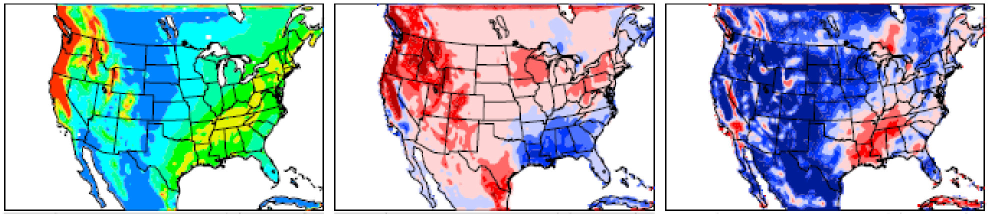
The SWAT model in PNAS ! (IF=9.737)



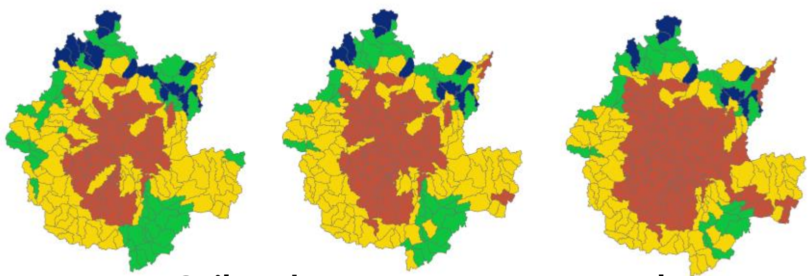


night

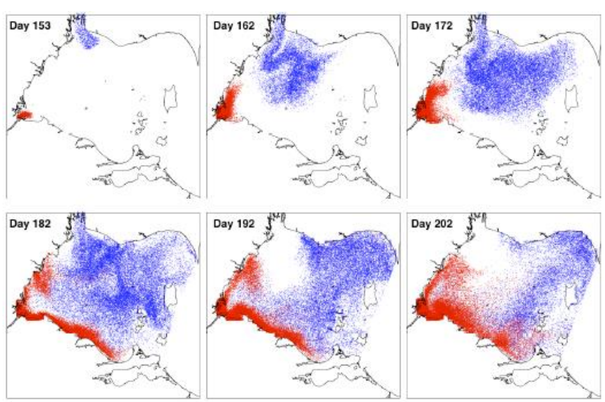
Modeling approach



RegCM-CLM model (Dynamic downscaling)



Soil and Water Assessment Tool
(Hydrologic and WQ model)



Lake Circulation model

Climate change Model

Meteorological condition

Watershed Model

Pollutant Loading

Lake Circulation Model

Water quality, HABs

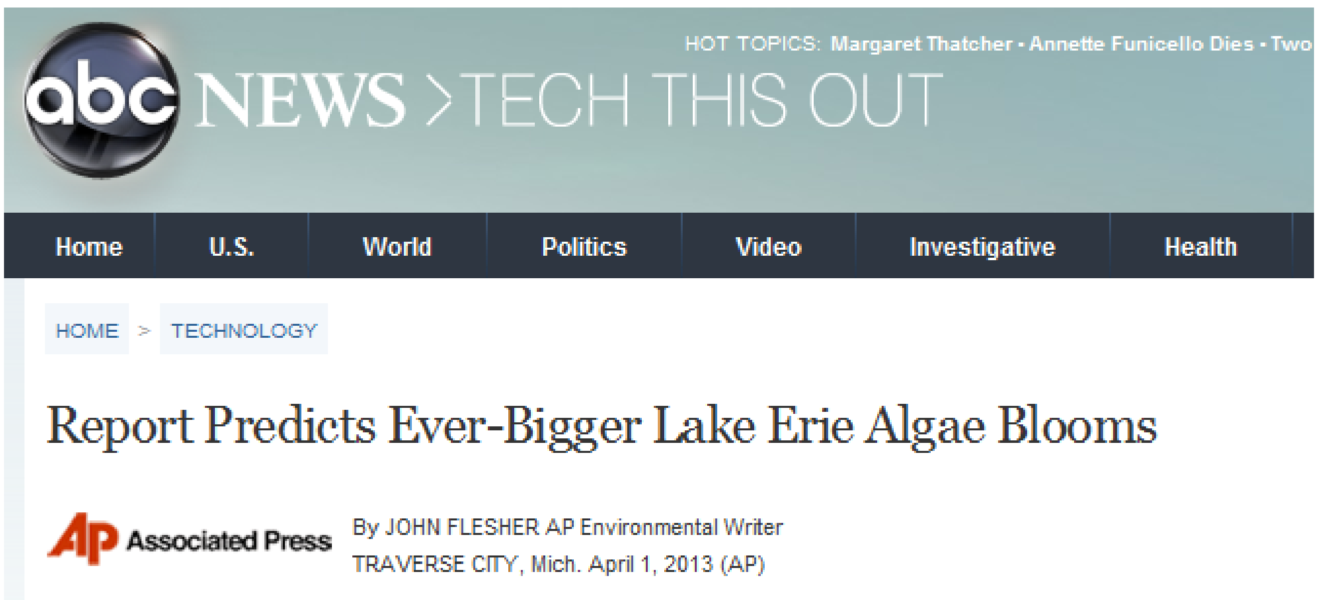
Our study in Media

AP

"It was the largest algae bloom in Lake Erie's recorded history "

TIME
Science & Space

" A lot of management practices that were put in place in the '80s improved things for a while, but we're shifting into this warmer world and we need new practic…"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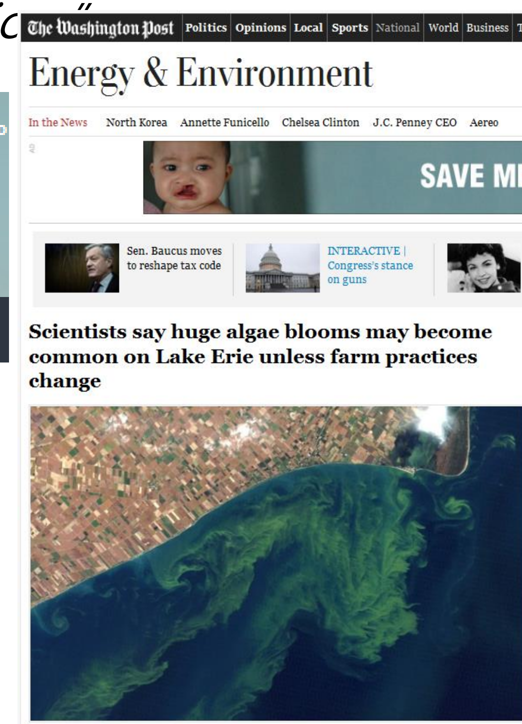
Report Predicts Ever-Bigger Lake Erie Algae Blooms

AP Associated Press

By JOHN FLESHER AP Environmental Writer

TRAVERSE CITY, Mich. April 1, 2013 (AP)

ABC news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INTERACTIVE | Congress's stance on guns

Scientists say huge algae blooms may become common on Lake Erie unless farm practices change

Washington post

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