REVIEW ON MODELING FATE AND TRANSPORT OF FECALLY-DERIVED MICROORGANISMS AT THE WATERSHED SCALE: STATE OF THE SCIENCE AND FUTURE OPPORTUNITIES

Kyung Hwa Cho a , **Yakov A. Pachepsky** b, * , David M. Oliver c , Richard W. Muirhead d , Yongeun Park b , Richard S. Quilliam c , Daniel R. Shelton b

a School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology, Ulsan, 689-798, South Korea

b USDA-ARS, Environmental Microbial and Food Safety Laboratory, 10300 Baltimore Ave. Building 173, BARC-EAST, Beltsville, MD 20705, USA

c Biological & Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK

d Land & Environment, AgResearch Ltd, Invermay Research Centre, Private Bag 50034, Mosgiel 9053, New Zealand

OUTLINE

- Introduction
- Overland module
- In-stream module
- Groundwater module
- Conclusion

INTRODUCTION

- Natural waters serve as habitat for a wide range of microorganisms, a proportion of which may be derived from fecal material.

- Fecally-derived microorganisms (FMs) include pathogens, and microbes that are not pathogenic but do indicate the presence of fecal contamination, e.g. Escherichia coli and enterococci, commonly referred to as fecal indicator organisms

- The presence of FMs in an aquatic environment indicates that a contamination pathway has connected a fecal source in the landscape to the water environment.

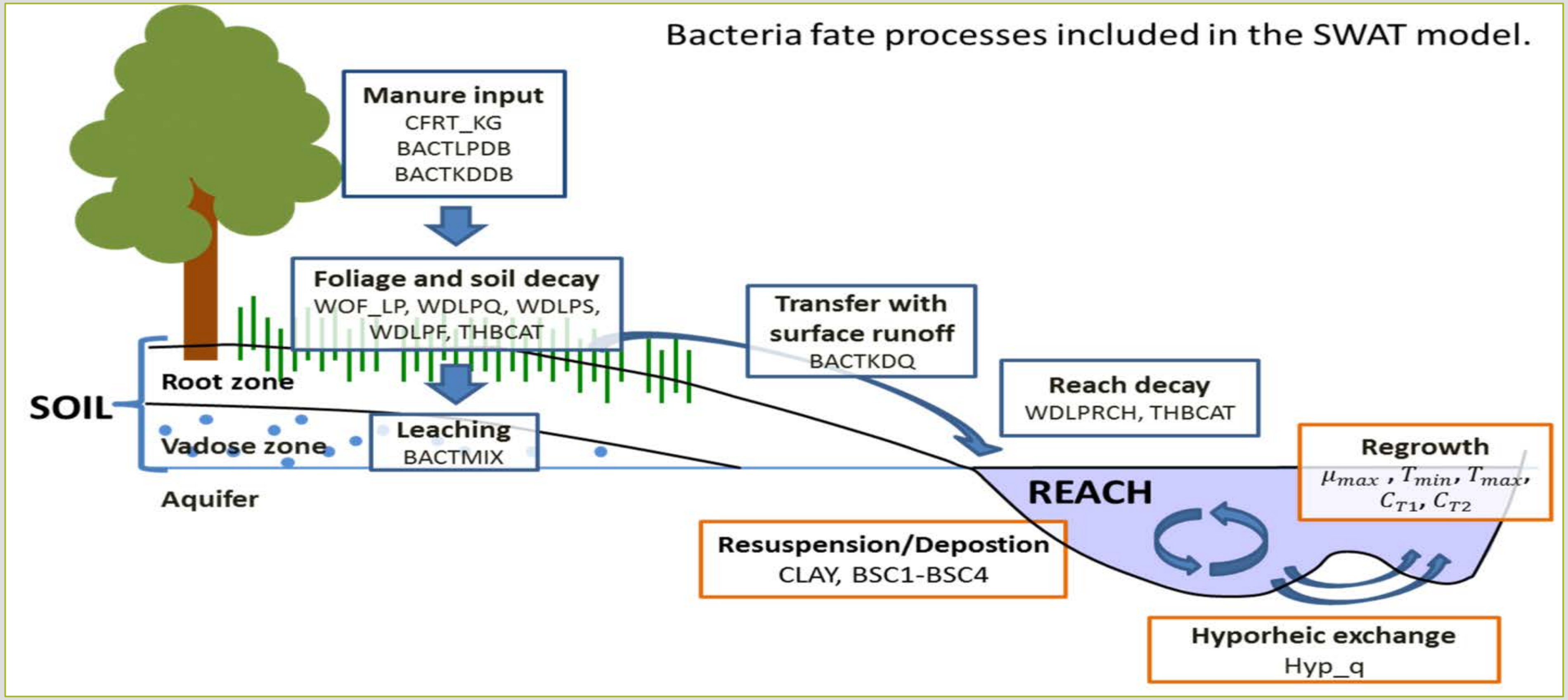
INTRODUCTION

- Various combinations of microbial fate and transport controls have led to the development of mathematical models capable of generating "what if" responses to a range of scenarios.

- Watershed-scale fate and transport modeling has the potential to help determine whether WQ standards can be met under site specific weather and management conditions,

- The aim of this review is to highlight and critically evaluate developments in modeling of microbial water quality over the last 10 years, and to discuss directions for model development and application, with a particular focus on FIOs

SWAT MODULE

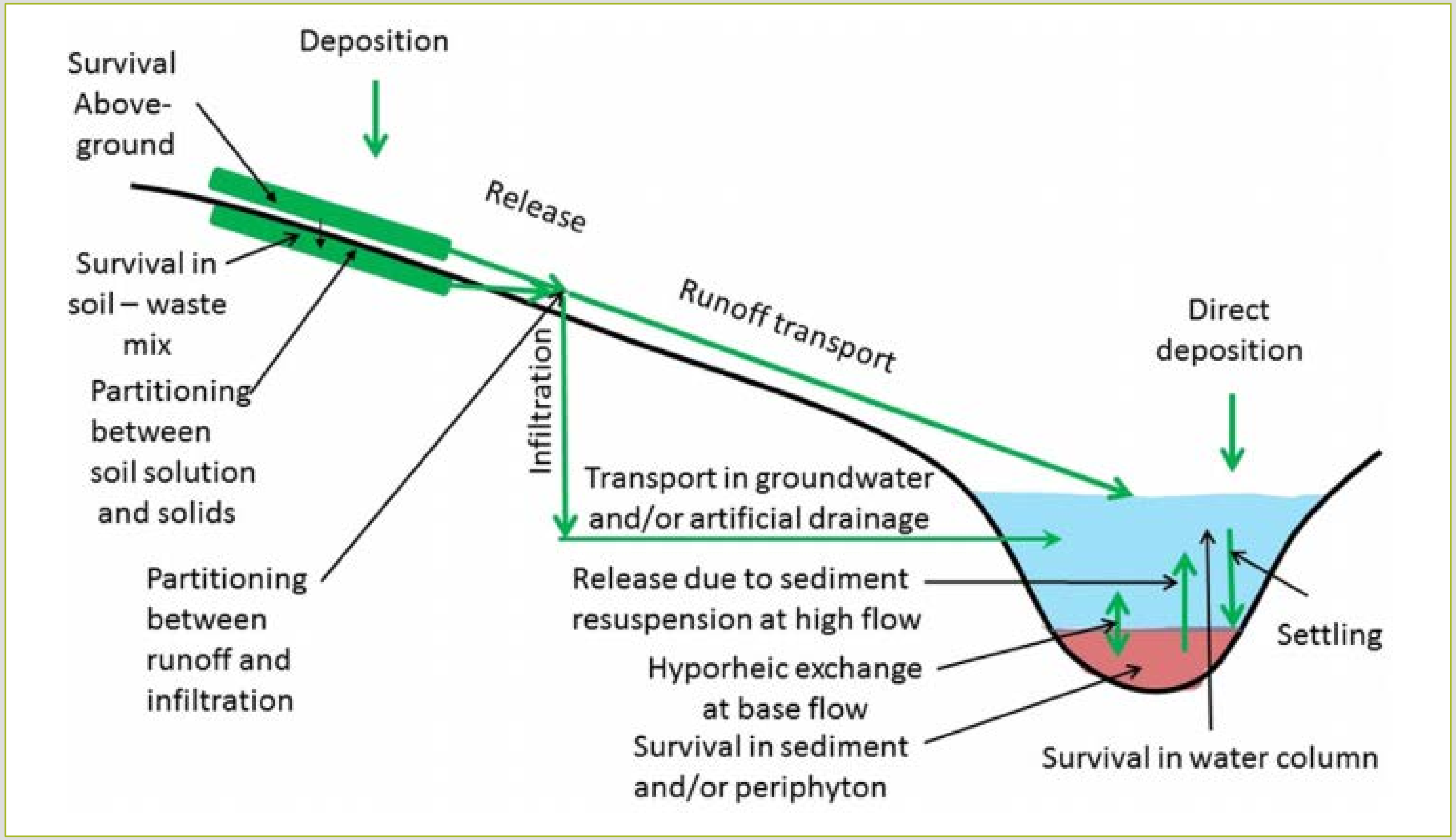


KIM et al., 2016, Under review

1. No biological kinetics on bacteria in Fecal Reservoir
2. Bacteria in Leaching are assumed to be all died.
3. Only die-off in in-stream module

PATHWAY OF FECAL MICROOGANISM

Pathway of fecal microorganisms including surface runoff from soil to survival in surface water bodies; green lines represent the pathway of fecal microorganism release and transport and black lines point to specific fate-related process that need to be modeled.



OVERLAND
-SURVIVAL IN FECAL RESERVOIR-

- Oliver et al. (2010) reported that the use of first-order kinetic equations could result in an underestimation of E. coli burden attributed to the land reservoir, mainly because of growth and re-growth of E. coli in feces post-defecation. The survival model suggested by Oliver et al. (2010) was

$$E_{(x)} = Ein_{(x)} + E_{(x-1)} \times e^{-b(x)} + ER_{(x)}$$

- where E(x) is the total number of the E. coli stored at a pasture on day x (CFU or MPN), Ein is the E. coli input of fresh deposits (CFU or MPN), b is the die-off rate on day x (), and ER is the magnitude of daily E. coli growth for the same day (CFU or MPN).

OVERLAND
-SURVIVAL IN FECAL RESERVOIR-

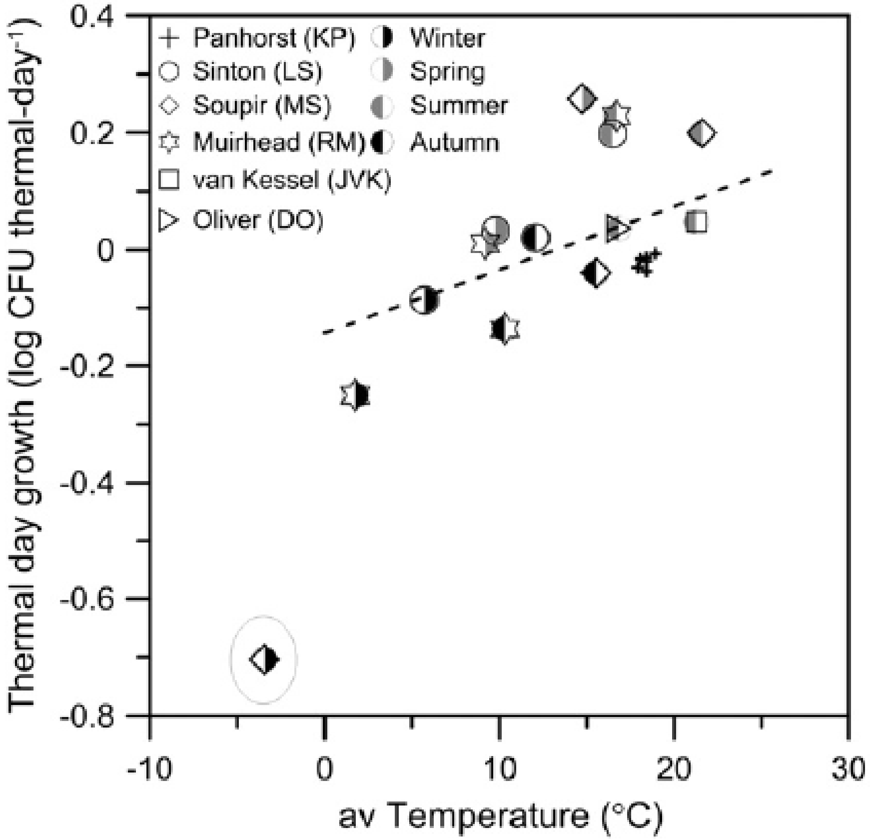


Fig. 3. Dependence of thermal day growth rate during the first week of sampling and the average temperature for that period. MS—winter data was not used in the regression.

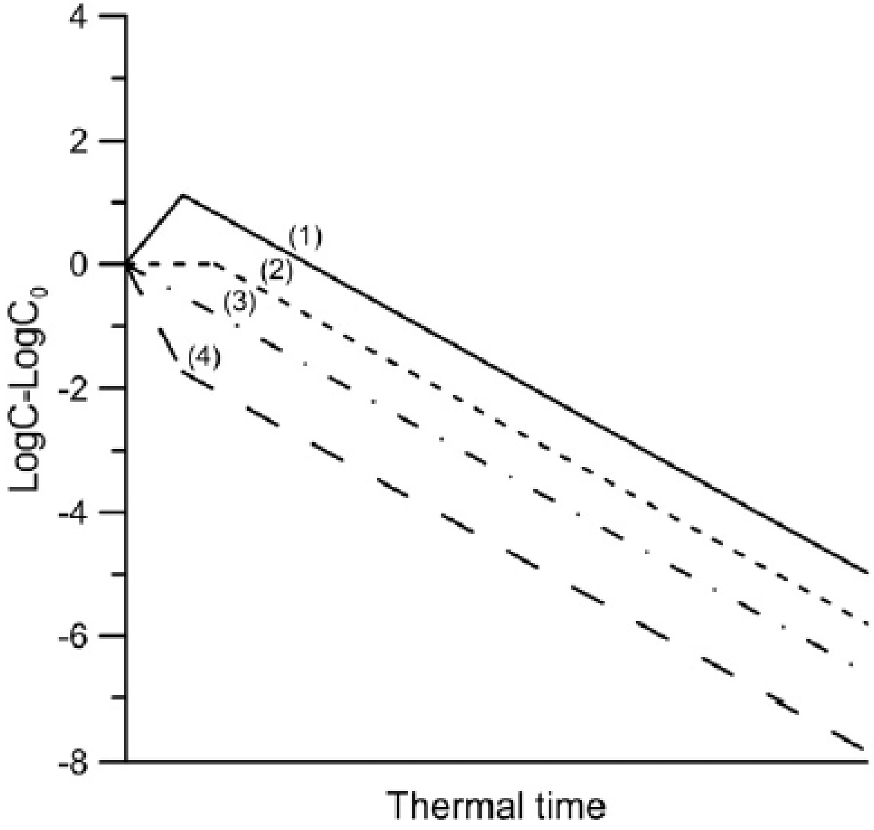
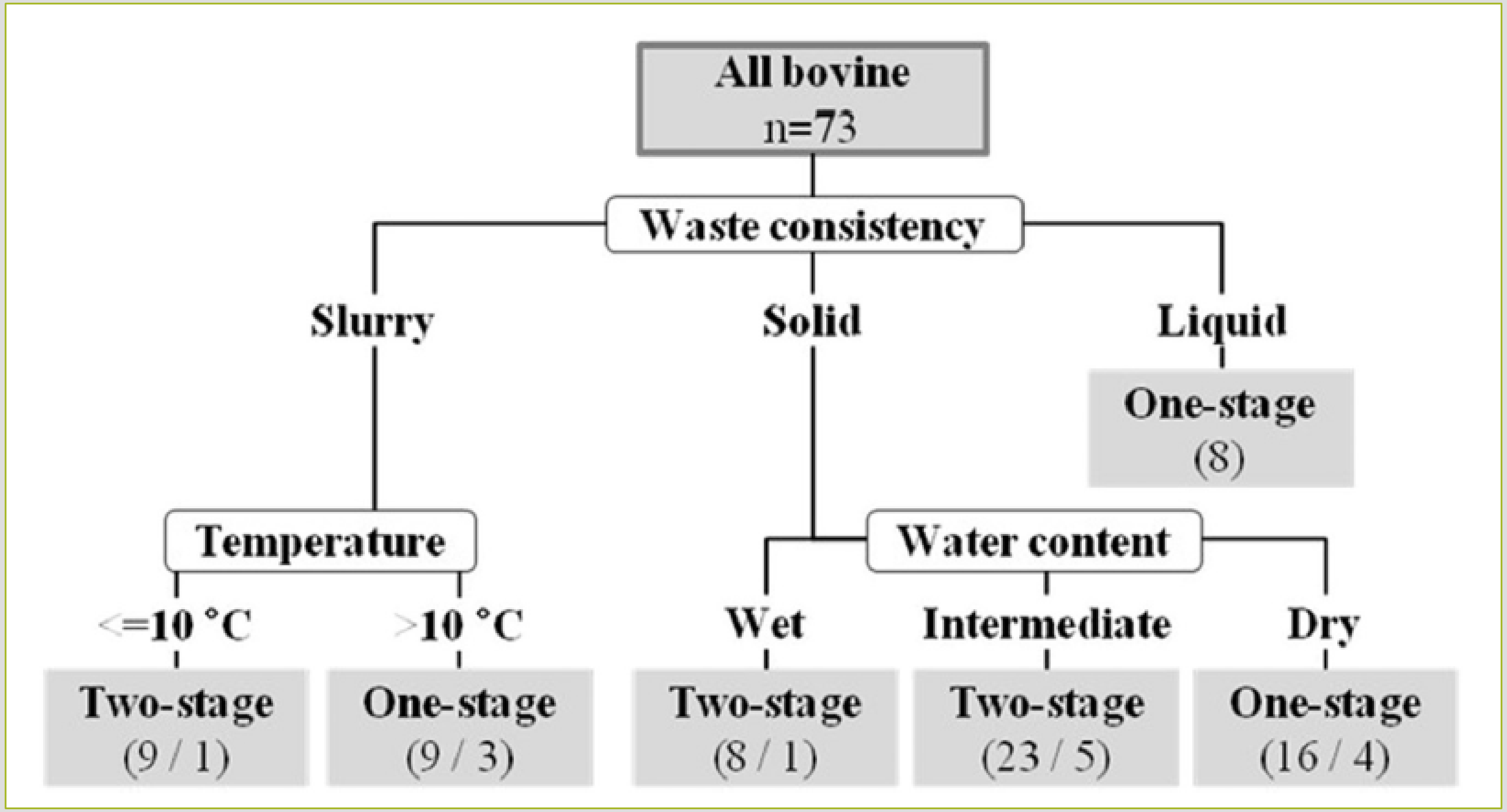


Fig. 6. Proposed models to conceptualize *E. coli* survival in cowpats with two-stage dynamics where the second stage shows first-order inactivation kinetics. First-stage cases are (1) initial growth, (2) constant population, (3) no initial stage, and (4) fast decay.

Martinez et al., 2013

OVERLAND
-SURVIVAL IN SOIL RESERVOIR-

The decision tree to predict the type of the survival kinetics for E. coli in bovine animal waste in soil. Numbers in parentheses mean "total number of datasets with the kinetics stated above/the number of datasets where the opposite type of kinetics occurs)

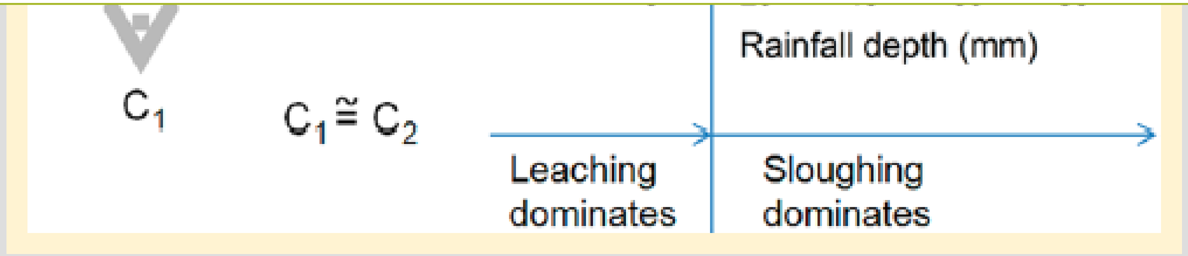


Park et al., 2015

SURFACE RUNOFF
-BACTERIAL RELEASE-

Table 2. Microbial release models.†

Model	Total number of released organisms	Differential equation for the total number of released organisms	Concentration in the released suspension
Exponential (Bicknell et al., 1997)	$\frac{N}{N_0} = 1 - \exp(-k_e W)$	$\frac{1}{N_0}\frac{dN}{dW} = k_e \frac{N_0 - N}{N_0}$	$\frac{d(CV)}{dW} = k_e (CV - C_0 V_0)$
Bradford-Schijven (B-S) (Bradford and Schijven, 2002)	$\frac{N}{N_0} = 1 - \frac{1}{(1 + k_p \beta W)^{\frac{1}{\beta}}}$	$\frac{1}{N_0}\frac{dN}{dW} = k_p \left(\frac{N_0 - N}{N_0}\right)^{1+\beta}$	$\frac{d(CV)}{dW} = k_p (C_0 V_0 - CV)^{1+\beta} (C_0 V_0)^{-\beta}$
Vadas-Kleinman-Sharpley (VKS) (Vadas et al., 2004)	$\frac{N}{N_0} = AW^n$	$\frac{1}{N_0}\frac{dN}{dW} = AnW^{n-1}$	$\frac{1}{C_0 V_0}\frac{d(CV)}{dW} = AnW^{n-1}$



Typical pattern of bacterial releases, Blaustein et al 2015

IN-STREAM
-DIE-OFF-

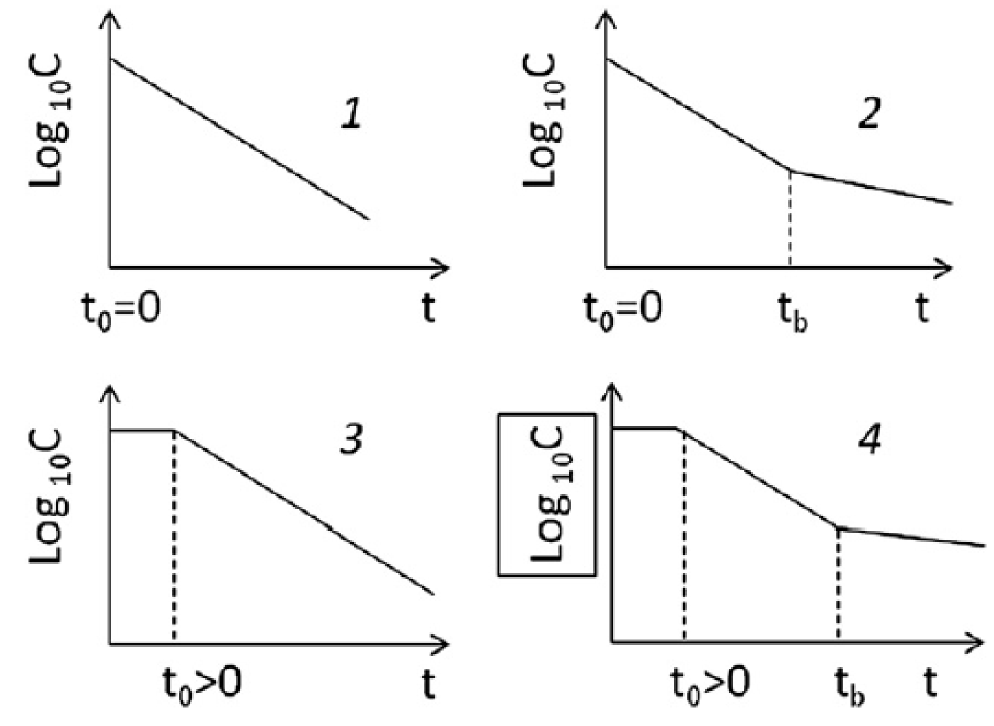
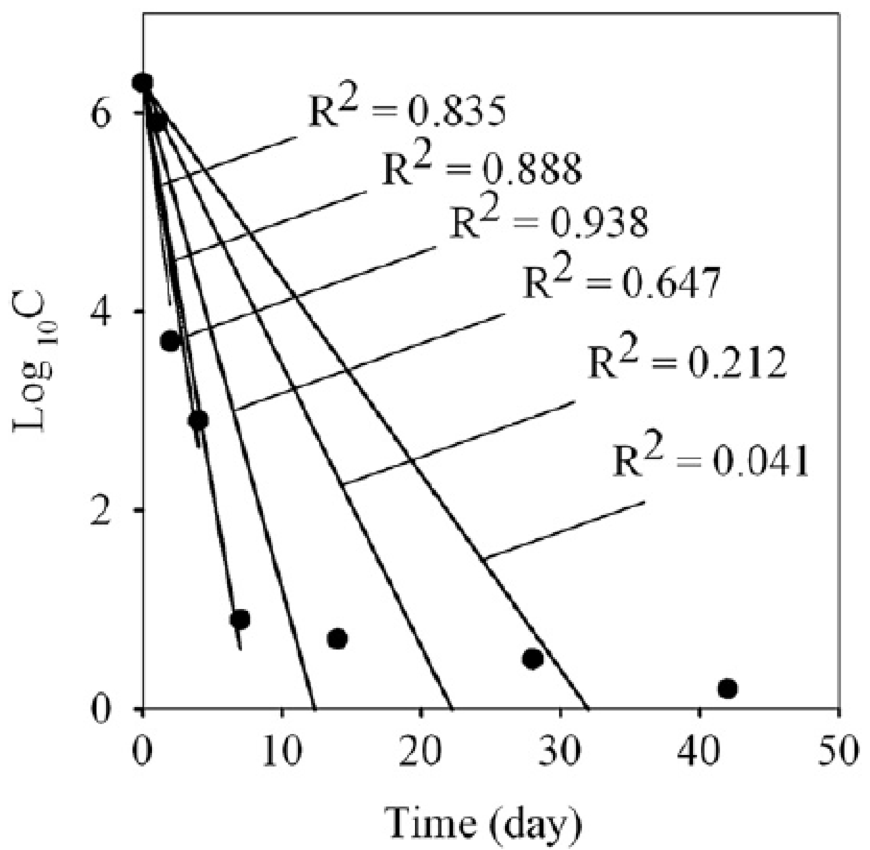


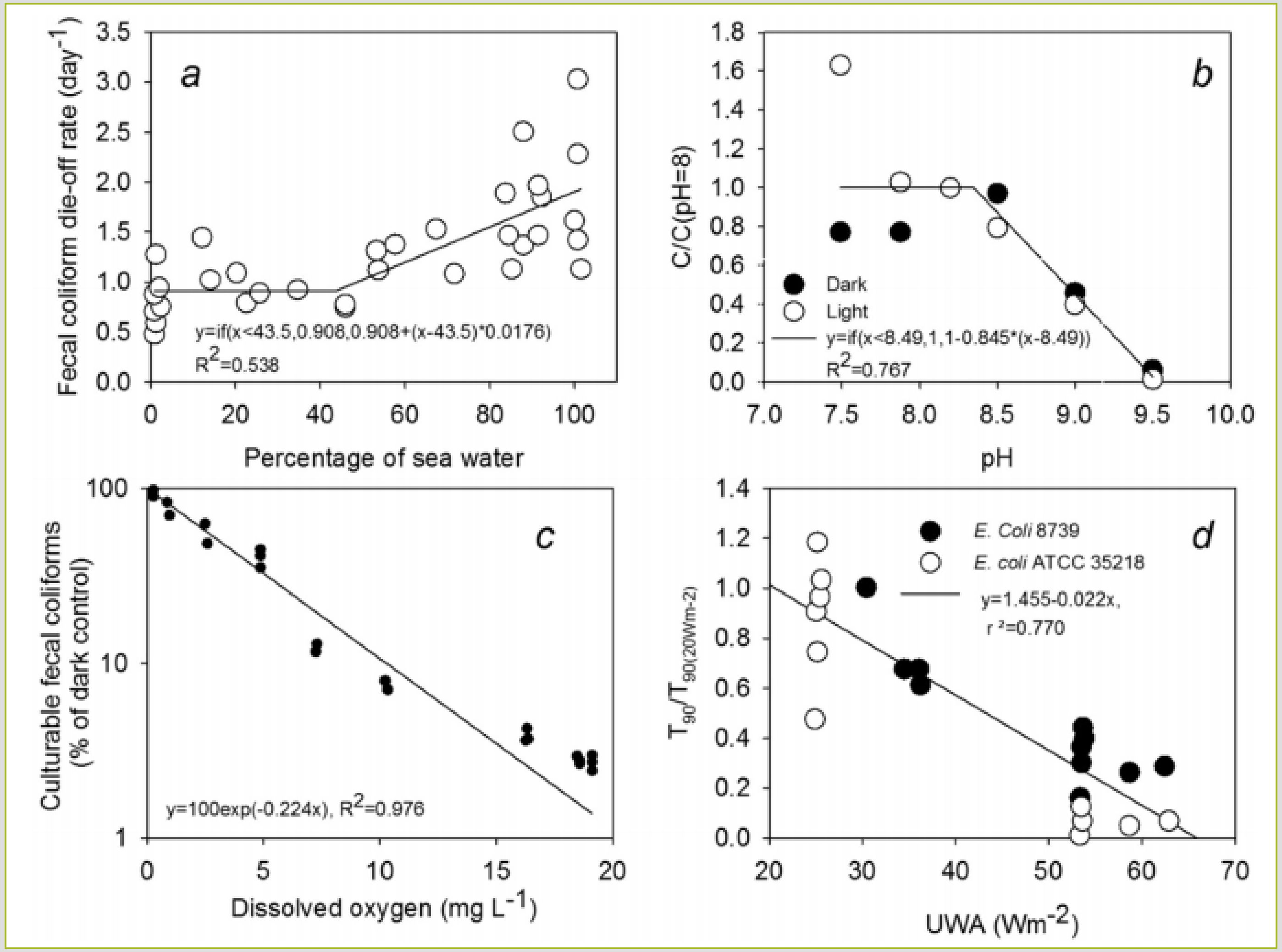
Fig. 1 – Patterns found in data on *E. coli* inactivation in waters.



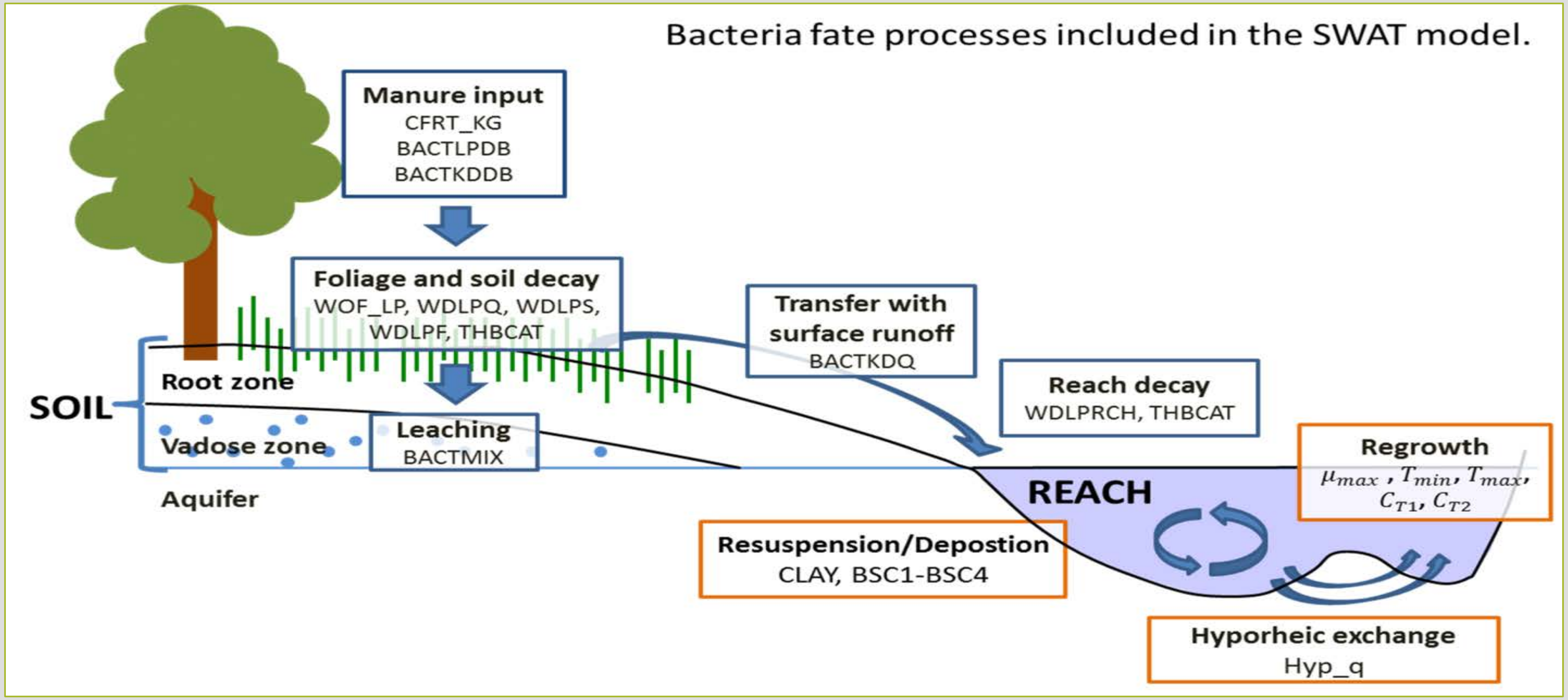
Blaustein et al 2013

IN-STREAM
- ENVIRONMENTAL EFFECTS ON E. COLI SURVIVAL-

. Environmental effects on E. coli survival.
(a) Effect of water salinity on coliform survival (data from Mancini, 1978);
(b) effect of pH on bacteria survival in light and dark conditions in waters from the waste stabilization pond (experimental data from Curtis et al., 1992);
(c) effect of oxygen concentration on the impact of light on bacteria concentrations; the samples (pH 8.8) received 7.83 MJ m2 for 136 min (¼960 W m2) (experimental data from Curtis et al., 1992);
(d) decrease in relative T90 with the increase in UV radiation level for two strains of E. coli in water from retention pond (data from Jozic et al., 2014).



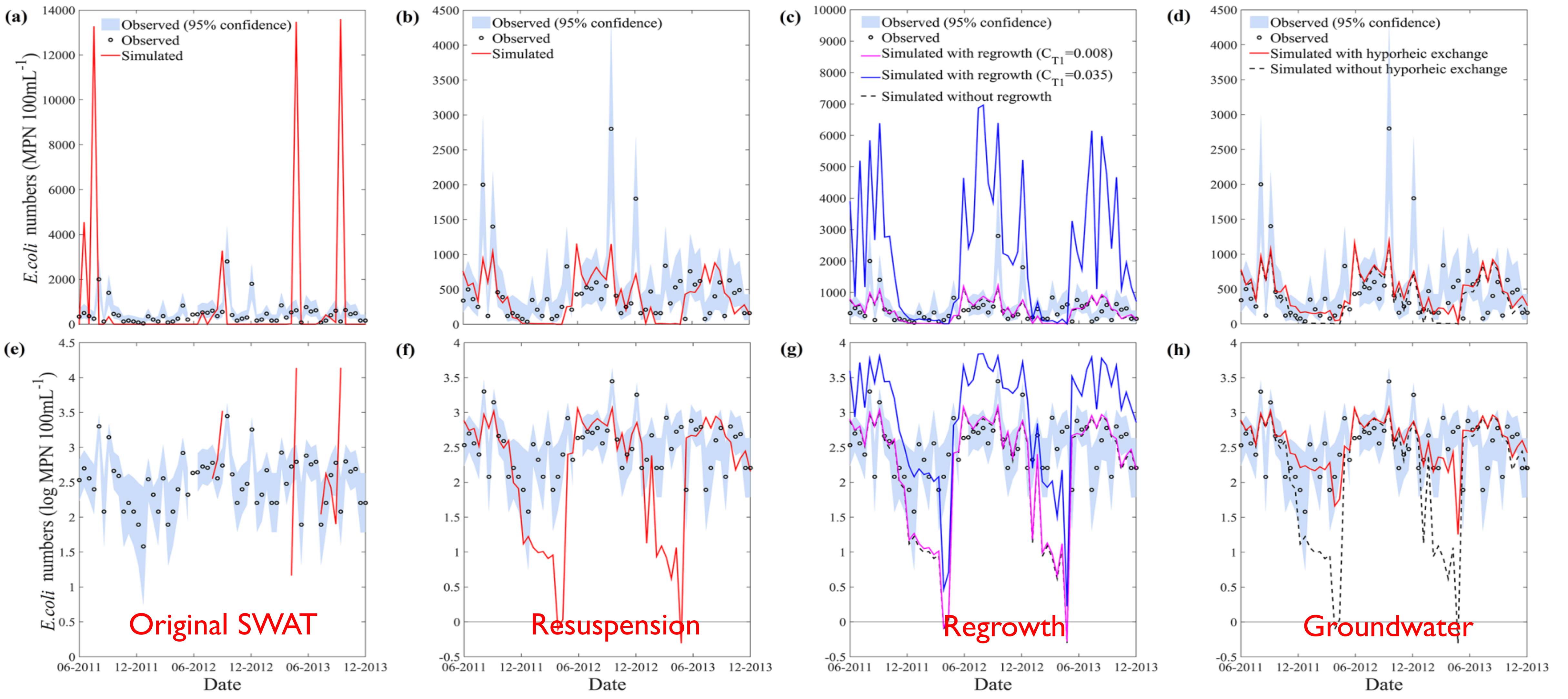
GROUNDWATER CONTRIBUTION



KIM et al., 2016, submitted

GROUNDWATER CONTRIBUTION

KIM et al., 2016, Under review



CONCLUSION

- Many efforts have been made to simulate FIOs using hydrological models including SWAT.
- But, it is oversimplified in terms of bacteria kinetics in overland and water environment, and quantification of bacteria runoff.
- The uncertainty reduction in modeling results has to be targeted and can be achieved via active experimentation with and monitoring of overland, groundwater, and underlying bed sediment-related fate and transport of fecal microorganisms

THANK YOU FOR YOUR ATTENTION

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Review

Modeling fate and transport of fecally-derived microorganisms at the watershed scale: State of the science and future opportunities

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