

Increasing the Understanding of Pathogen Removal Ecosystem Service by Aquatic Ecosystems to Improve Water Sustainability

Tao Huang¹, Wilfred M Wollheim^{1,2}, and Robert J Stewart²

¹Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH 03824, USA

²Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824, USA



INTRODUCTION

Outbreak of waterborne disease is a worldwide water quality issue, waterborne diseases cause health, social, and economic problems (Grabow, 1996).

The application of dynamic hydrologic models to simulate the pathogen loads and removal in varied aquatic ecosystems is still limited.

Rationale:

Human development has a significant impact on water quality, and quantifying this impact is critical.

Dynamic watershed-scale models are needed to understand the sources, transport and fate of pathogens and the consequences for water quality at broad regional scales and how they vary over time.

Research questions:

What are the relationships between pathogen concentration and land use and hydrologic conditions?

Are stream networks important regulators of pathogen transfer to critical water bodies?

What are the hotspot and hot moment of pathogen removal?

Hypothesis:

We hypothesize that pathogen concentrations entering river systems from land are positively correlated with residential and agricultural land use and hydrologic characteristics. Stream networks play an important role of the fate and transport of pathogen. The varied hydrologic conditions cause the difference of pathogen decay and lead to the variations of pathogen removal among aquatic ecosystems.

OBJECTIVES

To address the overarching question we will use a spatially distributed modeling approach that accounts for the location of sources, routing, water body types, and in-stream transformations.

STUDY AREA

This study assessed the headwater and mainstem of the Merrimack and the Great Bay watersheds. Upstream of Merrimack River Watershed is mainly forest, while downstream and coastal areas are developed.

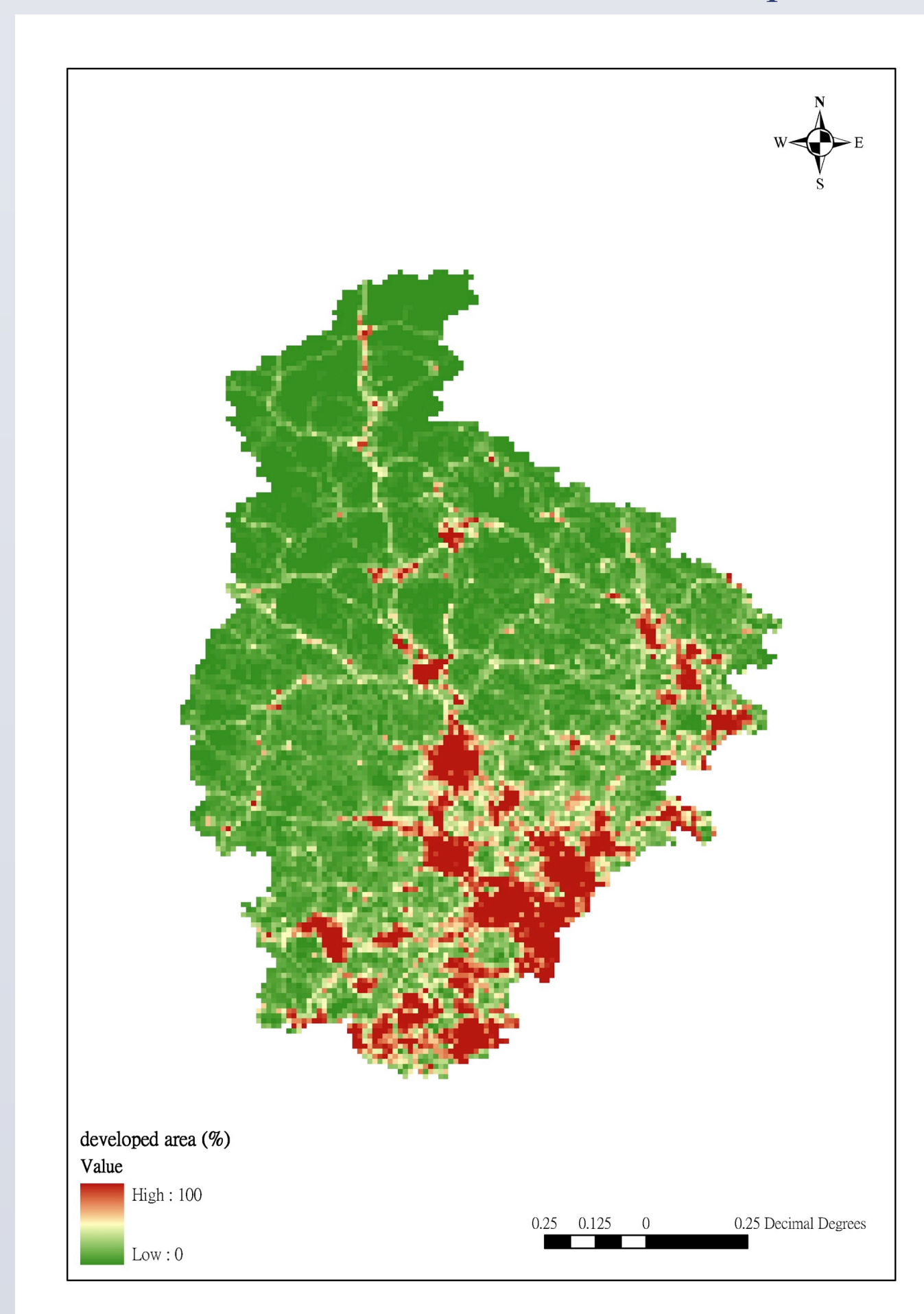


Fig 1. Developed area of Merrimack/Great Bay watershed

MATERIALS AND METHODS

The Framework for Aquatic Modeling in the Earth System (FrAMES) model was designed for simulating hydrology and biochemistry at various scales. We developed a pathogen module for the pathogen indicators in the FrAMES model, an existing spatially distributed river network model that accounts for storm runoff, routing, water temperature, land use effects, and serial processing in the river network.

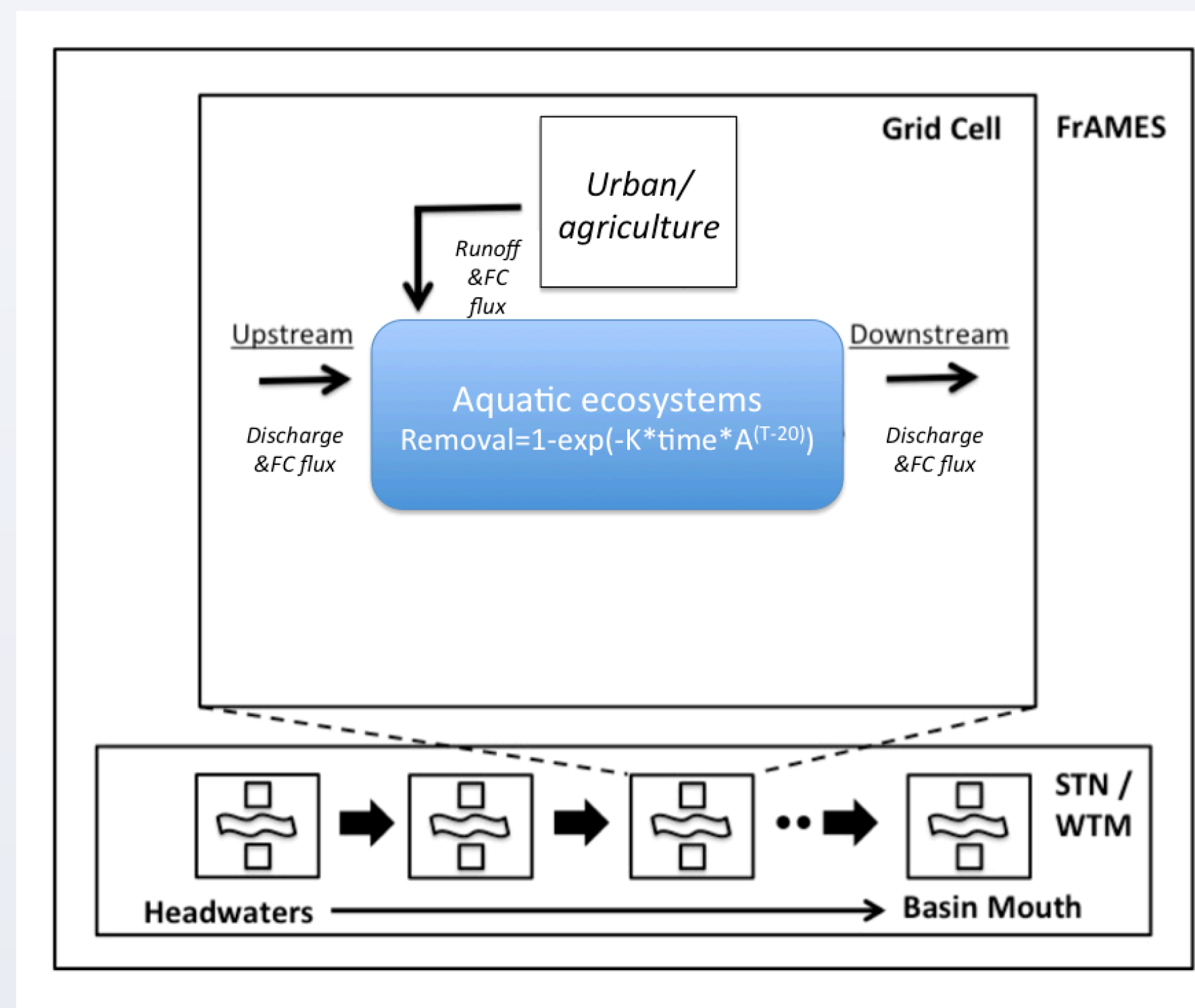


Fig 2. Conceptual model of the pathogen model

As Fig 2 shows, the pathogen module estimates pathogen from terrestrial loadings, removal in aquatic ecosystems, and the final concentration.

1. Local loadings of fecal coliform

The fate and transport of pathogens is affected by land use (Wilkes et al., 2011). This study uses impervious surface percentage to estimate the local loads of pathogens.

Fecal coliform concentration (CFU/100ml)

$=10^{1.4+0.05*\text{rainfall}+0.03*\text{impervious area fraction}*100+0.02*\text{air temperature}}$

Local loadings of fecal coliform (CFU/day)

$=\text{Runoff concentration of FC} * \text{Runoff volume}$

2. Aquatic removal

$C_t = C_0 * \exp(-K * \text{time} * A^{(T-20)})$

Removal efficiency $= (C_0 - C_t) / C_0 = 1 - \exp(-K * \text{time} * A^{(T-20)})$

Total mass of pathogen removed (CFU/d)

$= \text{removal} * (\text{Local loading of pathogen} + \text{pathogen from upstream})$

C_t : pathogen concentration at time t

C_0 : initial concentration of the pathogen

K: decay rate

Time: residence time

A: temperature adjustment factor

T: temperature

Input data:

Climate data were acquired from NASA's Global Modeling and Assimilation Office (Modern Era- Retrospective Analysis for Research and Applications, or MERRA).

Impervious surface data was acquired from National Land Cover Database 2006 (NLCD 2006).

RESULTS

We demonstrated this study with the simulation of year 2011. In this year, the precipitation is higher in mountainous areas and cause the higher runoff (Fig 3). Figure 4 shows the pattern of removal efficiency, small streams have higher fecal coliform removal efficiency due to longer residence time. The concentration of fecal coliform is higher in the southeastern area (Fig 5), because urban and suburban provide main sources of fecal coliform, including feces of wild animals, domestic animals, and human.

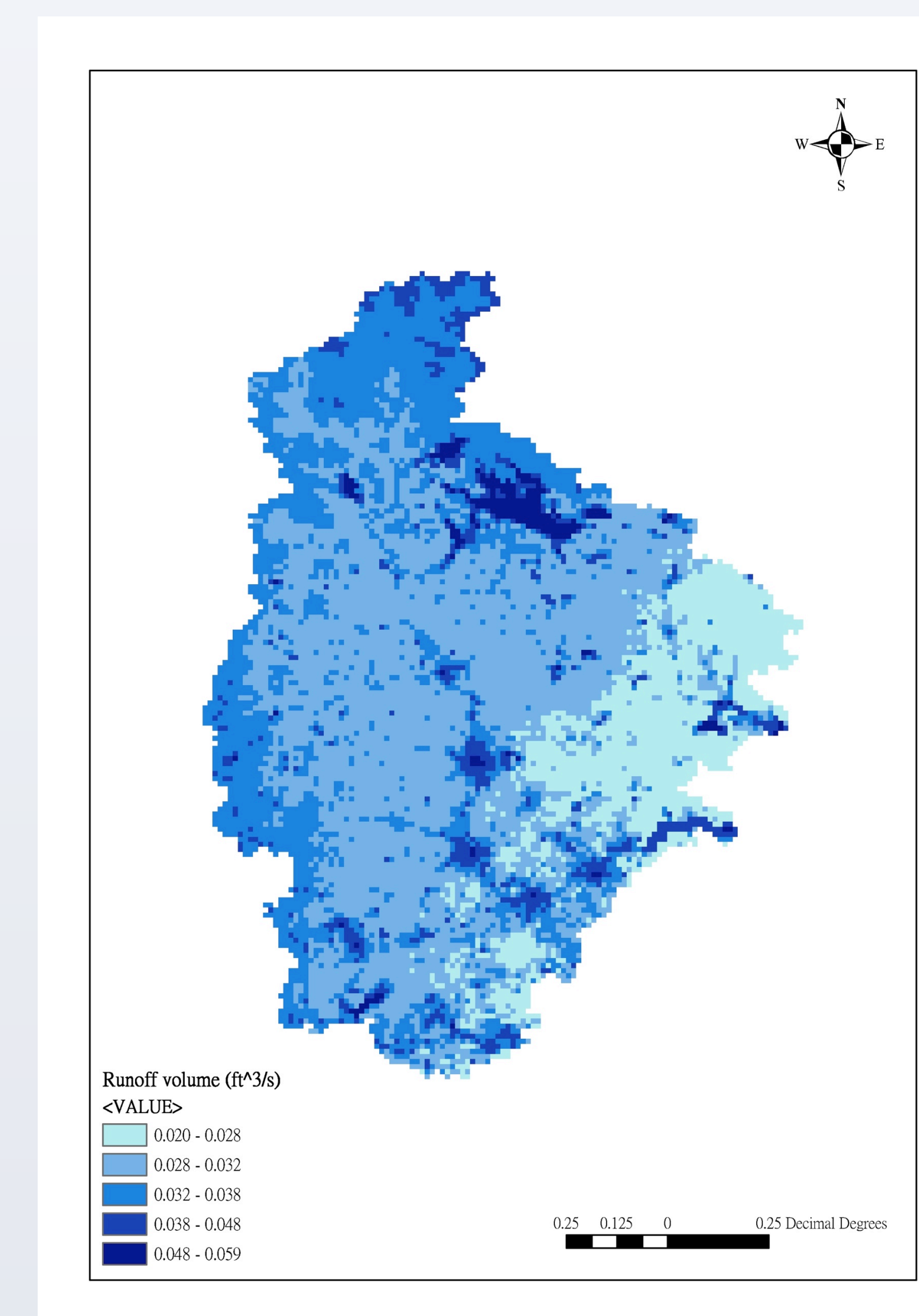


Fig 3. Runoff volume

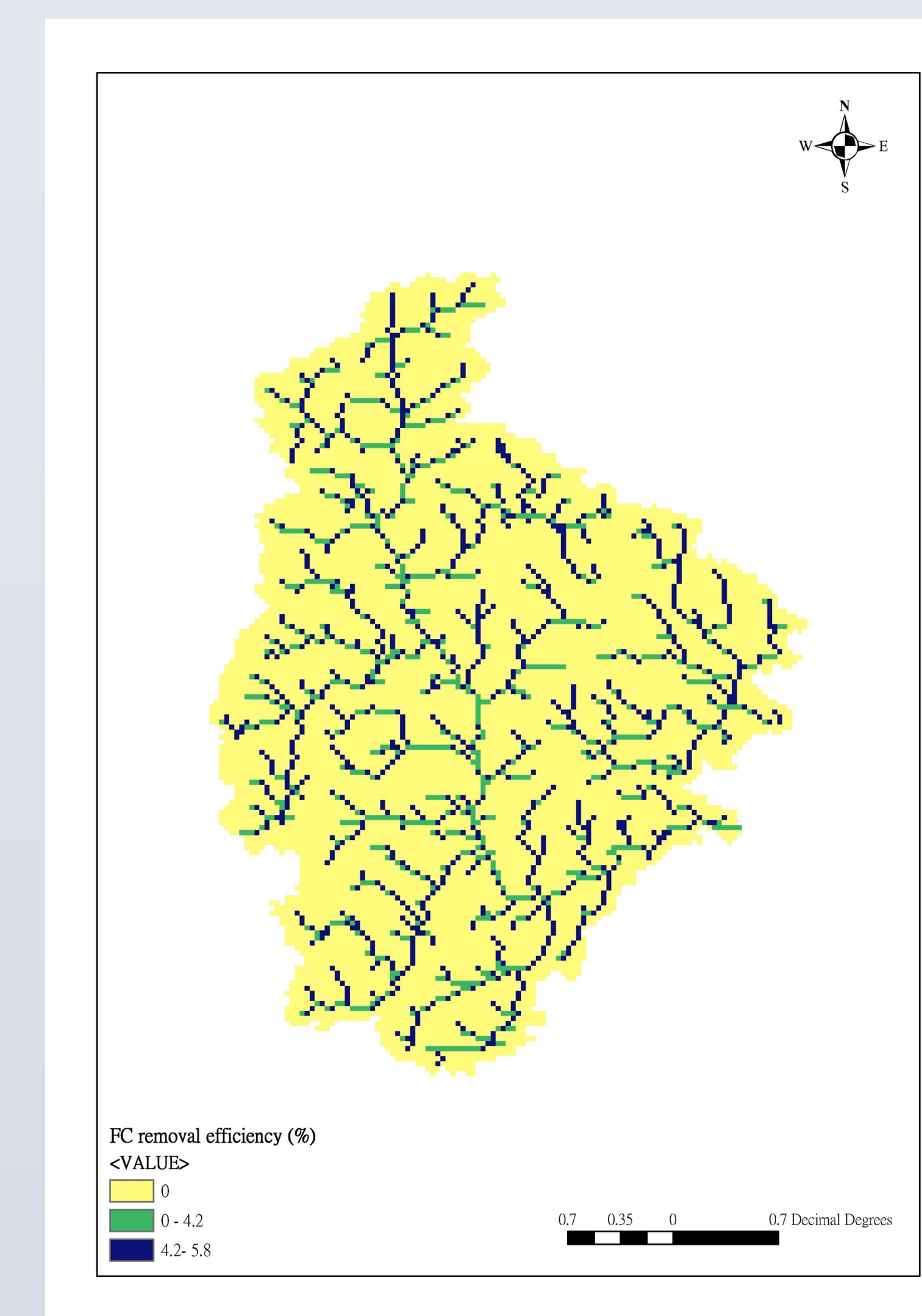


Fig 4. Aquatic removal efficiency

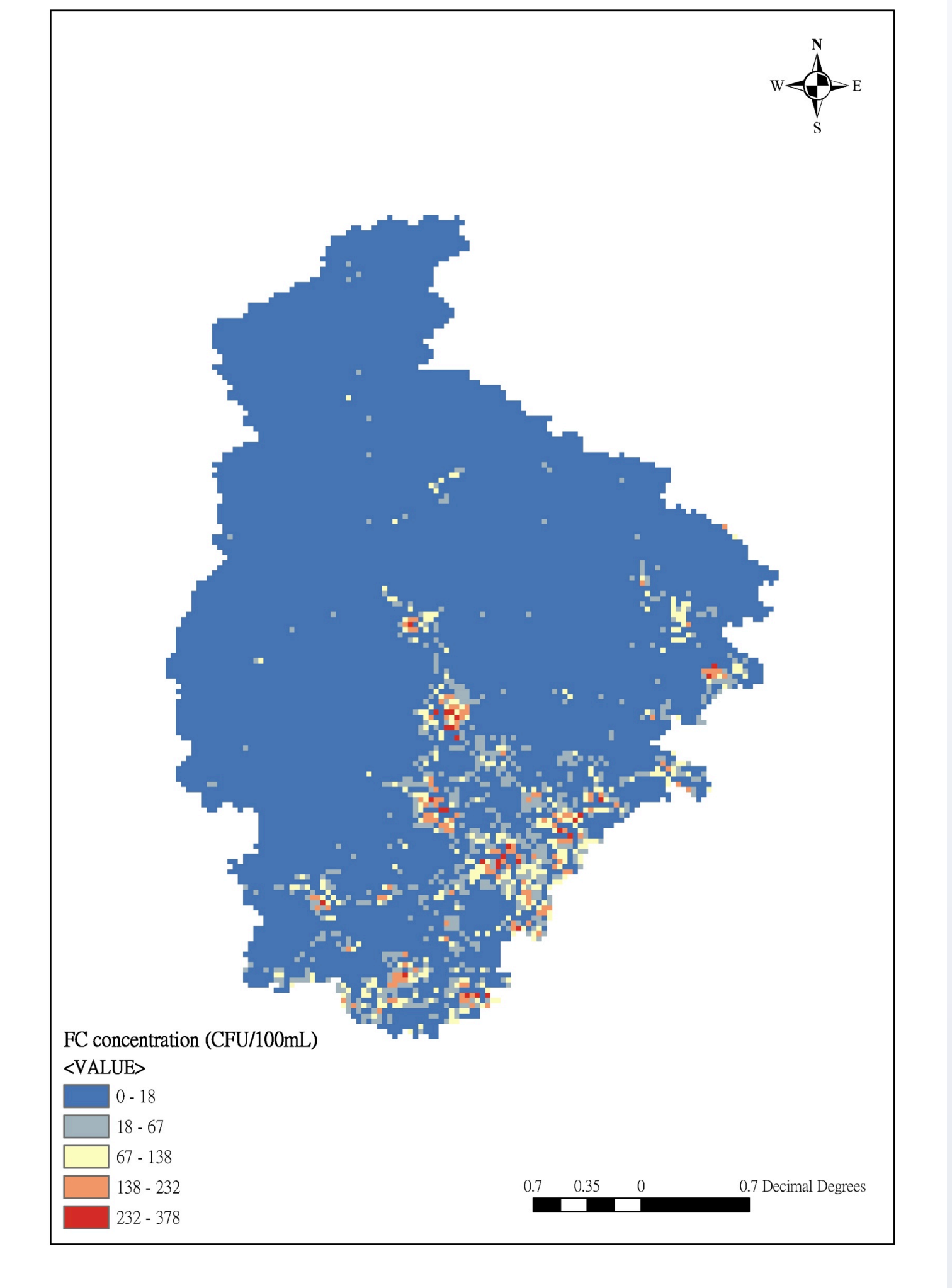


Fig 5. Fecal coliform concentration

SUMMARY AND FUTURE WORK

This study applied FrAMES model to simulate the fate and transport of the pathogen indicator- fecal coliform. Quantifying the ecosystem service of fecal coliform removal can provide information to decision makers. We found Small streams have higher fecal coliform removal efficiency due to longer residence time, and the fecal coliform concentration of runoff is not surprisingly higher in developed area. Future works include (1) validation of fecal coliform concentration, (2) analysis the fecal coliform at multiple spatial and temporal scales, (3) prediction of fecal coliform concentration under future land use and climate change scenarios.

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