# Evaluation of Phosphorus and Microbe Treatment of an In-Stream Bioreactor and a Natural Wetland in the North Carolina Piedmont

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## Abstract

Surface waters downgradient from septic systems have been shown to contain elevated phosphate and fecal indicator bacteria (FIB). Surface and subsurface bioreactors have been used to facilitate denitrification extensively in agricultural applications; however, few studies have quantified treatment of phosphate and FIB by these technologies downgradient of septic systems. The goal of this study was to quantify phosphate and FIB in water passing through an in-stream bioreactor (IBR) and a natural wetland (NW). The IBR was constructed in March 2017 and consists of a bed of woodchips and an adsorptive, Stalite media installed in the hyporheic zone of a drainageway receiving discharge from septic drainfields. Samples were collected from IBR inflow, interior, and outflow approximately monthly from March 2017 to March 2019. The NW was not modified and sample collection from inflow and outflow occurred monthly from November 2016 – March 2019. Results suggested that both BMPs effectively reduced concentrations and masses of phosphate and FIB. The IBR reduced phosphate concentrations and masses by 79% and 87%, respectively. Concentrations and loads of FIB from IBR outflow were 75% and 53% lower, respectively, than inflow. The NW reduced concentrations and masses of phosphate by 68% and 86%, respectively. FIB concentrations and loads from NW outflow were 55% and 66% lower, respectively, than inflow. These results suggested that BMPs could be modified to include adsorptive media, which may improve phosphorus and/or FIB treatment. Additionally, results from the NW suggest that these watershed features (e.g., wetlands, riparian buffers) should be accounted for when assessing transport of wastewater-derived nutrients and FIB.

## Introduction

What are natural and nature-based features? Why study them?

- These features (Fig. 1) provide important ecosystem services (e.g., pollutant abatement, stormwater management, habitat, etc.) that can improve water quality.
- Robertson & Merkley (2009) designed the first in-stream bioreactor that removed approximately 78% of nitrate from agricultural flows.
- Previous research in North Carolina found that septic systems can input significant nutrients and bacteria to surface waters in septic-dominated watersheds (Line 2013; Ferrell & Grimes 2014; Humphrey et al. 2015; Iverson et al. 2015, 2017, 2018).
    - Thus, retrofitting best management practices (BMPs) in nutrient-sensitive areas with elevated septic system densities could improve water quality.

The goal of this study was to quantify phosphate and *Escherichia coli* reductions from natural and nature-based BMPs.

Figure 1. Photos of the in-stream bioreactor during installation (A) and the natural wetland (B).

## Materials and Methods

An IBR was installed in March 2017 within a septic-dominated watershed (SEP1; Fig. 2) that drains to nutrient-sensitive waters. Woodchips (Fig. 2B) were selected to provide organic carbon to facilitate denitrification, while the *Stalite* media (Fig. 2C) provided exchange sites for adsorption of phosphate. A NW, which was not modified, was also studied to quantify how natural systems treat septic-derived nutrients.

Water samples were collected approx. monthly from the IBR (Mar 2017 – Mar 2019), the NW (Nov 2016 – Mar 2019) and from Lick Creek upstream and downstream of BMPs (Nov 2016 – Mar 2019). Nutrient were analyzed at the Environmental Research Laboratory at ECU. *E. coli* concentrations were enumerated using the *IDEXX* method.

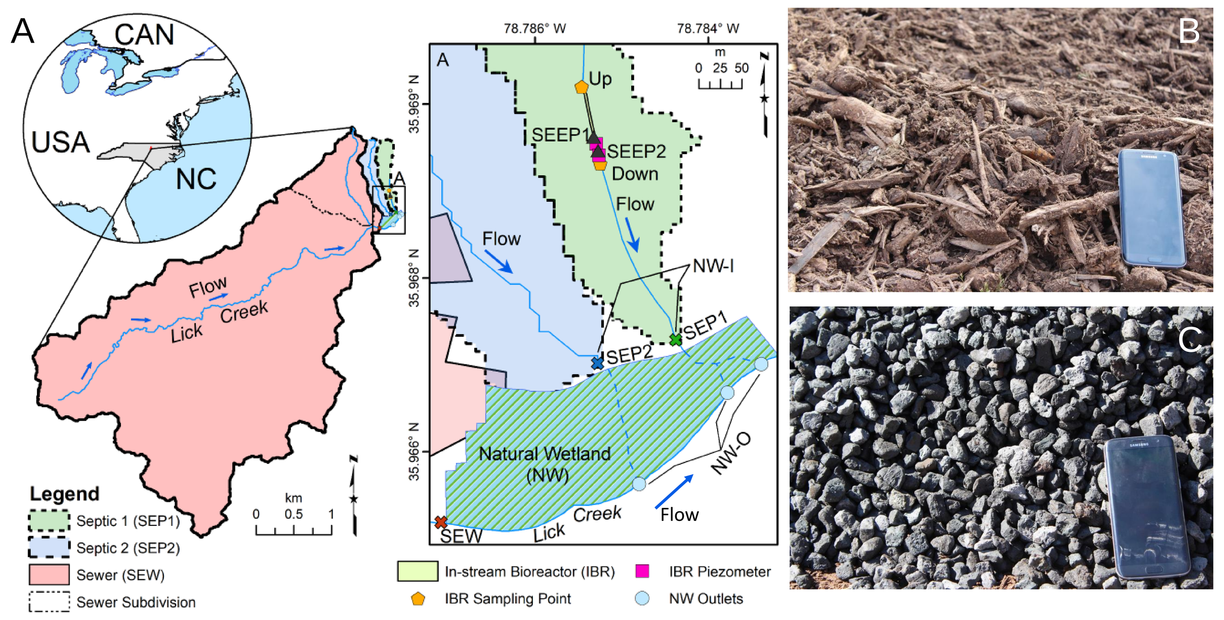


Figure 2. A) Watershed boundary map and location of in-stream bioreactor (IBR). B) Woodchip media; C) *Stalite* media.

## Results & Discussion

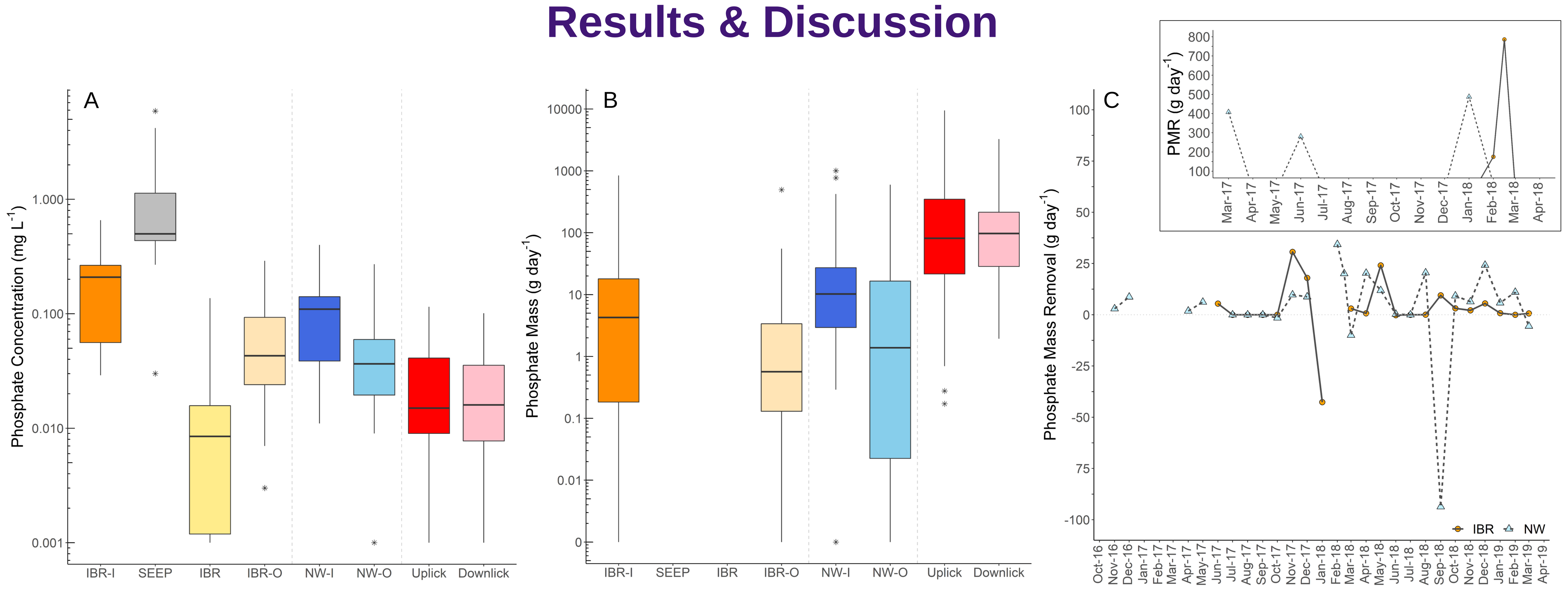


Figure 3. Boxplots of concentrations (A) and masses (B) of phosphate in water in inflow (I) and outflow (O) of the in-stream bioreactor (IBR) and natural wetland (NW) and in surface water upgradient (Uplick) and downgradient (Downlick) of BMPs. Temporal trends in phosphate mass removal (PMR) by the IBR and NW were also shown (C), the inset figure shows outliers when PMR substantially increased.

Figure 4. Photos of the stream before (left) and after (middle) the in-stream bioreactor was constructed. The photo on the right shows the natural wetland during a winter season.

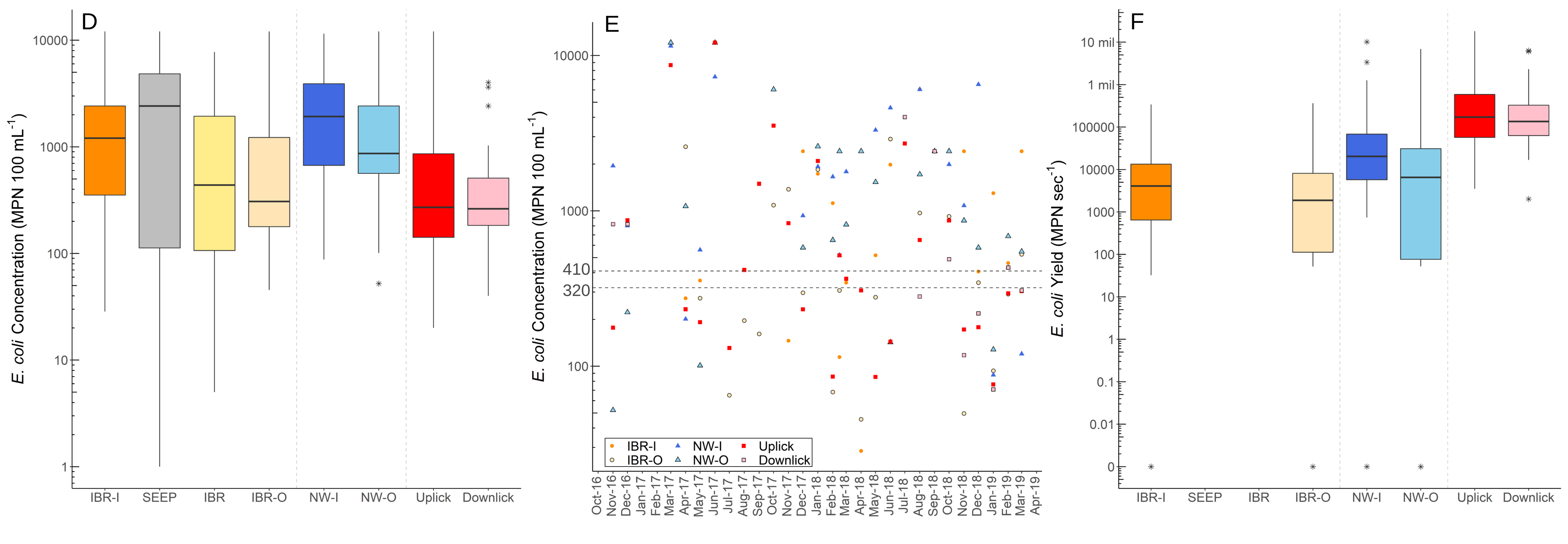


Figure 5. Boxplots of *E. coli* concentrations (D and E) and yields (F) in water in the inflow (I) and outflow (O) of the in-stream bioreactor (IBR) and natural wetland (NW) and in surface waters upgradient (Uplick) and downgradient (Downlick) of BMPs. Figure 5E shows *E. coli* concentrations relative to the statistical threshold value of 410 and 320 MPN 100 mL$^{-1}$ *E. coli* set by the US EPA (2012).

**Phosphate ($PO_4$-P) Treatment (Figures 3A – 3C)**

- Median concentrations of $PO_4$-P reduced by 79% and 68% after passing through the IBR and NW, respectively (Fig. 3A).
    - IBR reduced $PO_4$-P concentrations from 0.21 to 0.04 mg L$^{-1}$ (p< 0.01).
    - NW reduced $PO_4$-P concentrations from 0.11 to 0.04 mg L$^{-1}$ (p= 0.01).
- Surface water masses of $PO_4$-P reduced by 87% and 86% after passing through the IBR and NW, respectively (Fig. 3B).
    - IBR reduced median $PO_4$-P masses from 4.3 to 0.6 g day$^{-1}$ (p= 0.16).
    - NW reduced median $PO_4$-P masses from 10.2 to 1.4 g day$^{-1}$ (p= 0.06).
- Mass removal of $PO_4$-P tended to increase during cooler periods (e.g., Oct – Feb; Fig. 3C), although likely related to flow (ρ= 0.39; p= 0.01) and not likely related to temperature (ρ= -0.03; p= 0.85).
- Median concentrations and masses of $PO_4$-P were similar upstream and downstream of BMPs (Figs. 3A and 3B).
    - Concentrations of $PO_4$-P upstream and downstream of BMPs were 0.02 mg L$^{-1}$ (p= 0.89).
    - Masses of $PO_4$-P were slightly greater downstream (97 g day$^{-1}$) than upstream (81.5 g day$^{-1}$), but this was not statistically significant (p= 0.99).

***E. coli* Treatment (Figures 5D – 5F)**

- Median concentrations of *E. coli* decreased by 75% and 55% after passing through the IBR and NW, respectively (Fig. 5D).
    - IBR reduced *E. coli* concentrations from 1210 to 308 MPN 100 mL$^{-1}$ (p= 0.12).
    - NW reduced *E. coli* concentrations from 1925 to 866 MPN 100 mL$^{-1}$ (p= 0.32).
- Geometric mean concentrations of *E. coli* were elevated in outflow from the IBR (439 MPN 100 mL$^{-1}$) and the NW (946 MPN 100 mL$^{-1}$) relative to the US EPA (2012) recreational water quality standards of 126 or 100 MPN 100 mL$^{-1}$.
- Geometric mean concentrations of *E. coli* in upstream (371 MPN 100 mL$^{-1}$) and downstream (315 MPN 100 mL$^{-1}$) also exceeded water quality standards.
- Furthermore, all comparison groups exceeded the statistical threshold value (STV) of 410 or 320 MPN 100 mL$^{-1}$ more than 10% of the time (Fig. 5E).
    - *E. coli* concentrations in IBR outflow > STV more than 40% of the time.
    - *E. coli* concentrations in NW outflow > STV 78% of the time for both values.
    - *E. coli* concentrations in Lick Creek > STV more than 40% of the time.
- Median yields of *E. coli* decreased by 53% and 66% after passing through the IBR and NW, respectively (Fig. 5F).
    - IBR reduced *E. coli* loadings from 4108 to 1892 MPN sec$^{-1}$ (p= 0.49).
    - NW reduced *E. coli* loadings from 20428 to 6558 MPN sec$^{-1}$ (p= 0.17).
- Median concentrations and yields of *E. coli* were similar upstream and downstream of BMPs in Lick Creek (Figs. 5D and 5F).
    - *E. coli* concentrations upstream (271 MPN 100 mL$^{-1}$) were similar to downstream (263 MPN 100 mL$^{-1}$; p= 0.81).
    - *E. coli* loadings upstream (171825 MPN sec$^{-1}$) were slightly greater than downstream loadings (135978 MPN sec$^{-1}$), but this difference was not statistically significant (p= 0.70).

## Conclusions

- Both BMPs were effective at reducing concentrations and masses of phosphate.
- Concentrations and yields of *E. coli* tended to decline after passing through BMPs, although these differences were not statistically significant – data highly variable.
- Geometric mean and STV values of *E. coli* were elevated in all comparison groups, suggesting these waters could be a threat to public health.
- Surface water upstream and downstream of the NW contained similar pollutant concentrations and masses, suggesting these systems may not be a significant source of phosphate and *E. coli* to Lick Creek.
- Results from the NW suggest that natural-based features should be accounted for when modeling watershed-scale nutrient budgets.
- Future work should include:
    - Increased flow ranges to isolate treatment thresholds for the IBR and NW
    - Microbial source tracking to identify possible sources of *E. coli* at all sites

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