Environmental and Public Health Impacts Resulting from Extreme Flooding Events

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September 5, 2019

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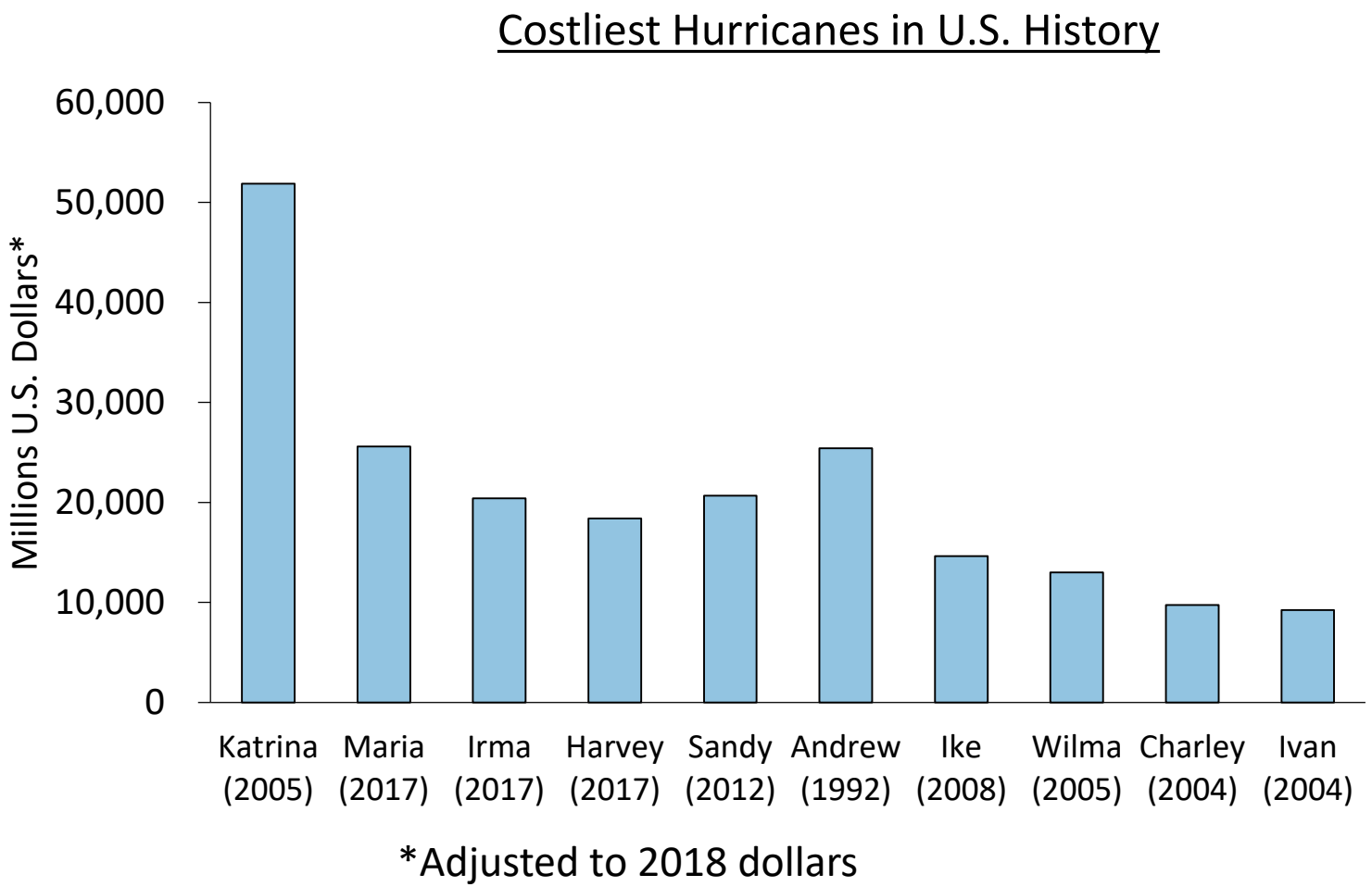
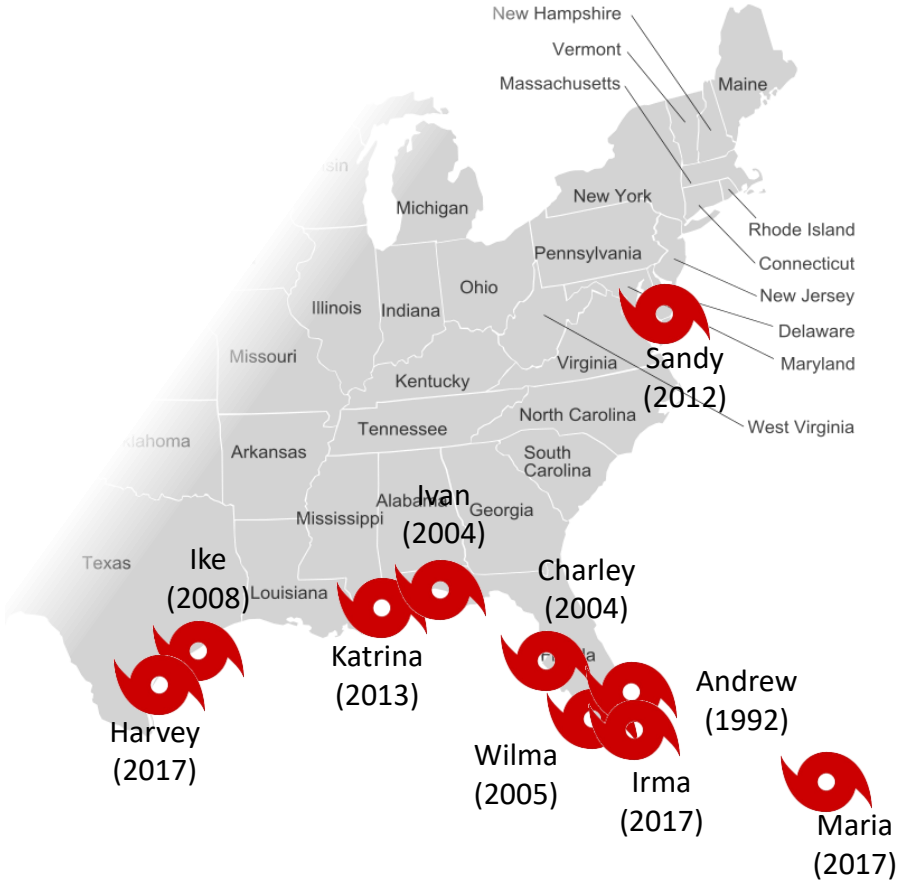
Overview

- Health Impacts and Human Exposures Associated with Flooding
- Toxic Exposures
- Waterborne Pathogens
- Emerging Challenges in Waterborne Pathogen Exposures: Case Studies in Antibiotic Resistance

Hurricanes: A Leading Cause of Flooding in the U.S.





Source: https://www.iii.org/fact-statistic/facts-statistics-hurricanes

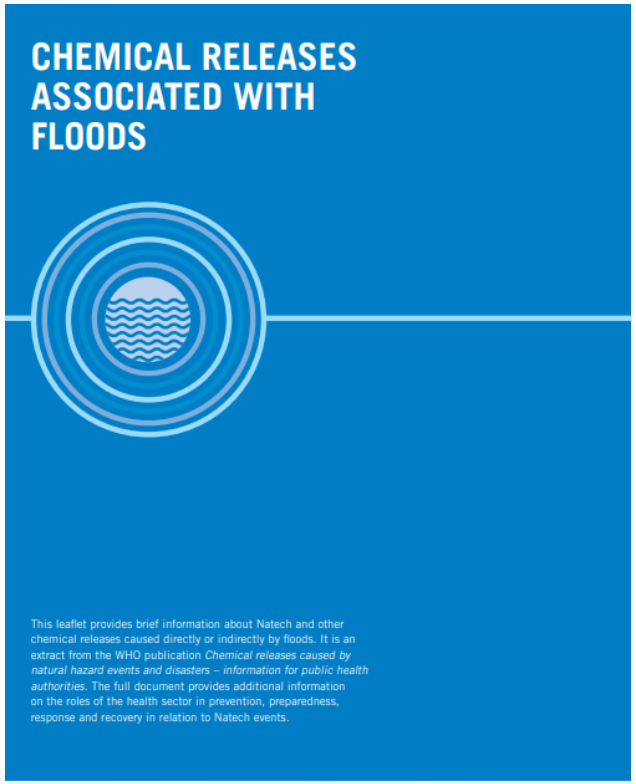
Health Impacts of Flooding

- Drowning (2/3 of flood related deaths)
- Acute Trauma
- Injuries
- Infrastructure Damage – loss of resources/access in health care facilities
- Mental Health and Psychological Impacts
- Communicable Diseases
- Vector-borne Diseases
- Waterborne Diseases
- Toxic Exposure

Environmental Exposures

Toxic Exposures

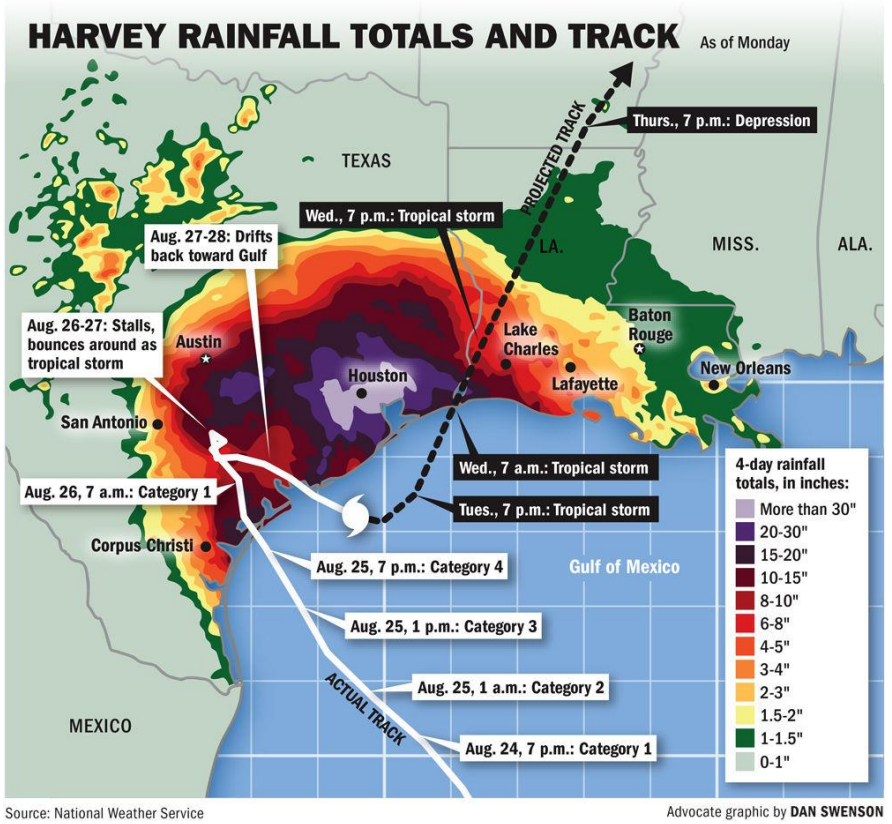
- Mechanisms of Chemical Release During Flooding
  - Disruption of storage tanks and rupturing of pipework
  - Toxic reactions and fire
  - Toxic runoff
  - Damage to power supply
  - Release of waste from chemical plants, mines, and dams
- Greatest risk to those living near industrial and agricultural storage



Toxic Exposures: Hurricane Harvey

- Over 100 toxic releases documented (Houston Chronicle)
- 7 Superfund sites flooding during Hurricane Harvey
- 8.3 million pounds of unauthorized air pollution (Environmental Integrity Project)
- Human and environmental health toll largely undetermined
- *Hurricane Harvey Registry* – partnership of local governments, Rice University, and National Institutes of Health to track health and other storm impacts

August 2017



Toxic Exposures: Hurricane Harvey

- Arkema chemical manufacturing plant, Crosby, Texas
  - Loss of power led to improper chemical storage
  - Multiple explosions
  - Fires (inaccessible by emergency crews) lasted several days
  - 200 people evacuated
  - 21 people sought medical treatment for exposure to fumes/smoke

Associated Press

Toxic Exposures: Hurricane Harvey

- U.S. Oil Recovery Superfund Site, Pasadena, Texas
  - Concrete tanks became flooded
  - Multiple discharges of carcinogenic compounds
- Magellan Midstream Partners
  - 461,000 gallons of gasoline leaked into Houston ship channel

Associated Press

Waterborne Disease Exposure After Flooding

- Unplanned Discharge of Sanitary Waste
  - Overflowing manure lagoons
  - Flooding of produce fields
  - Overwhelmed WWTPs
  - Combined sewer overflows

Associated Press

State of Ohio, Environmental Protection Agency

Waterborne Disease

- Fecal Pathogens
  - Typhoid Fever
  - Cholera
  - Hepatitis A
  - Dysentery
  - Enterotoxigenic *E. coli*
  - *Cryptosporidium*
- Leptospirosis – zoonotic pathogen transmitted through contact with skin and mucous membranes
- Necrotizing fasciitis (“flesh-eating bacteria”)
- Emerging Challenge: Antibiotic Resistance

How are Waterborne Diseases Transmitted?

- Contamination of drinking water facilities by elevated water levels
- Contamination of groundwater / Inundation of wells
- Contact with floodwater
- Largest risk occurs when significant populations are displaced (WHO)

Independent Record

Transmission of Disease by Contact with Floodwater

- Risks elevated even when flood water is not ingested
- Increased exposure to standing water
- Exposure to floodwater linked with increased incidence of gastrointestinal illness (Wade et al. 2004, *Am. J. Epidemiol*)
  - Highest Risk Activities
    - House or yard getting flooded
    - Walking through floodwater

American Journal of Epidemiology
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Vol. 159, No. 4
Printed in U.S.A.
DOI: 10.1093/aje/kwh050

Did a Severe Flood in the Midwest Cause an Increase in the Incidence of Gastrointestinal Symptoms?

Timothy J. Wade[1], Sukhminder K. Sandhu[2], Deborah Levy[3], Sherline Lee[3], Mark W. LeChevallier[4], Louis Katz[5], and John M. Colford, Jr.[2]

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Received for publication May 20, 2003; accepted for publication August 19, 2003.

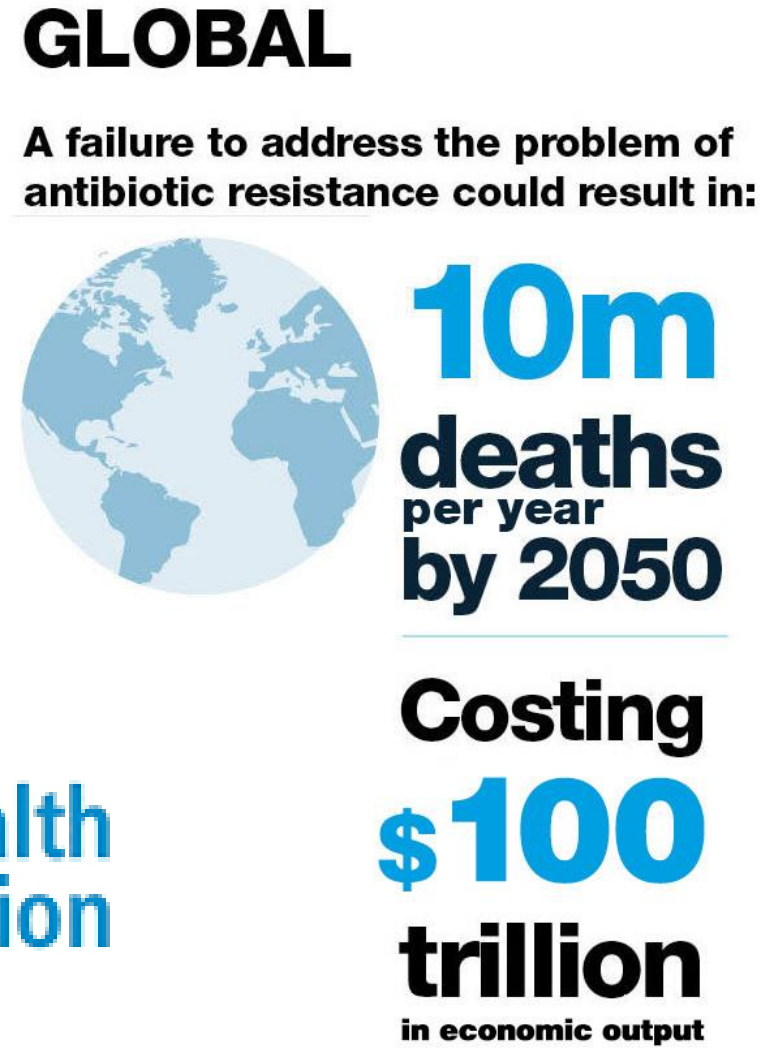
Transmission of Disease by Contact with Floodwater

- Leptospirosis – zoonotic pathogen transmitted through contact of urine from infected animals with skin and mucous membranes
  - Associated with rodent transmission (especially disturbances of rodent populations)
- Necrotizing fasciitis ("flesh-eating bacteria")
  - Causes: Group A *Streptococcus*, *E. coli, Staphylococcus aureus, Aeromonas hydrophila,* and members of the *Clostridium* and *Klebsiella* genera

ABC News

An Emerging Challenge: Antibiotic Resistance

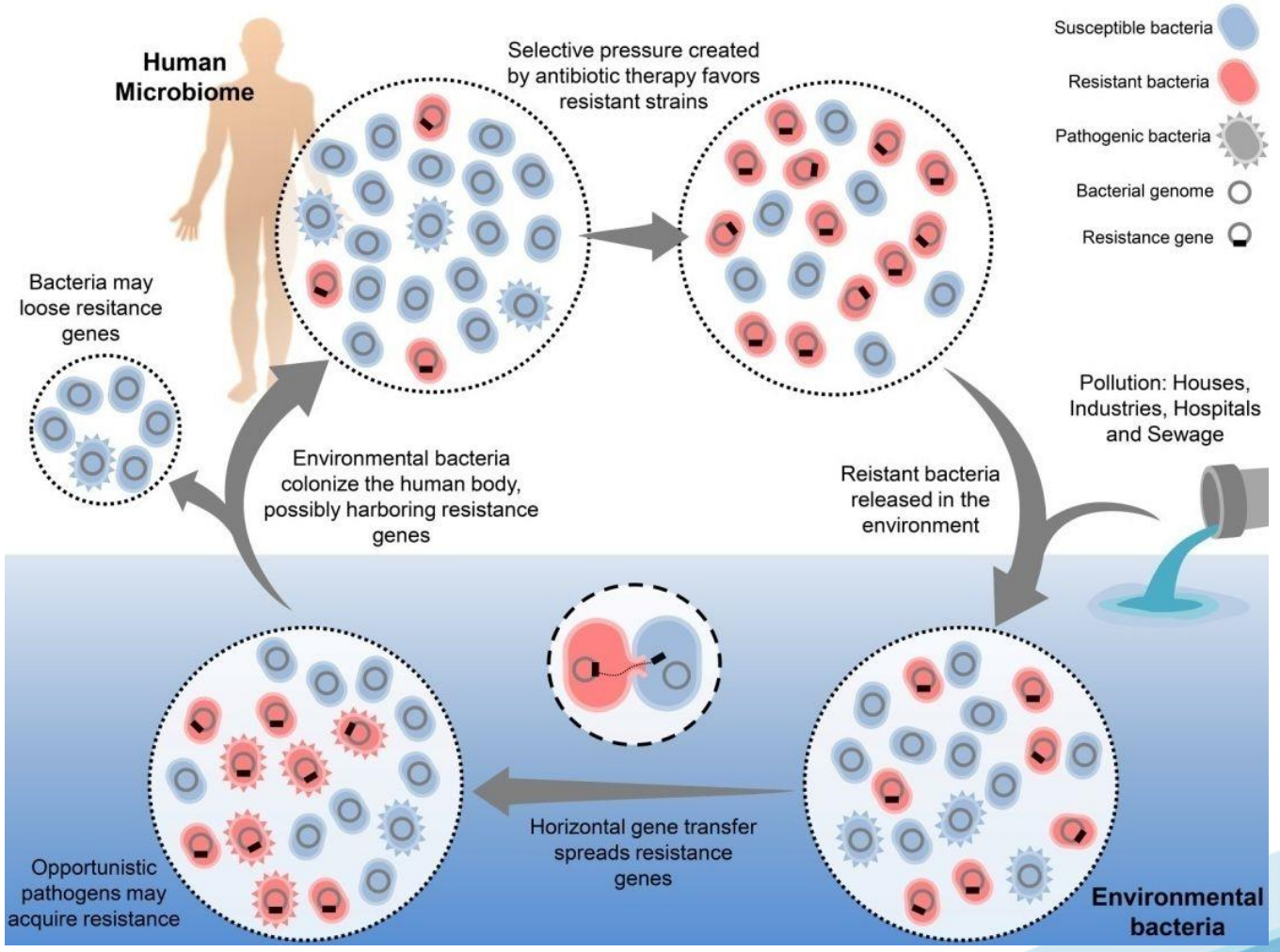
- World Health Organization: “Antibiotic resistance is one of the biggest threats to global health, food security, and development today.”
- Common infections becoming harder to treat
  - Longer hospital stays
  - Higher medical costs
  - Increased mortality



World Health Organization

Why Study Antibiotic Resistance in Flood Conditions?

- Increased input of sanitary waste to the environment
- Increased stress and selective conditions created by antibiotics, metals, pesticides, etc.
- Horizontal gene transfer → establishment of antibiotic resistant communities that persist after flooding



Coutinho et al., 2013, *Perspectives in Water Pollution*

Case Studies on Post-Flood Antibiotic Resistance

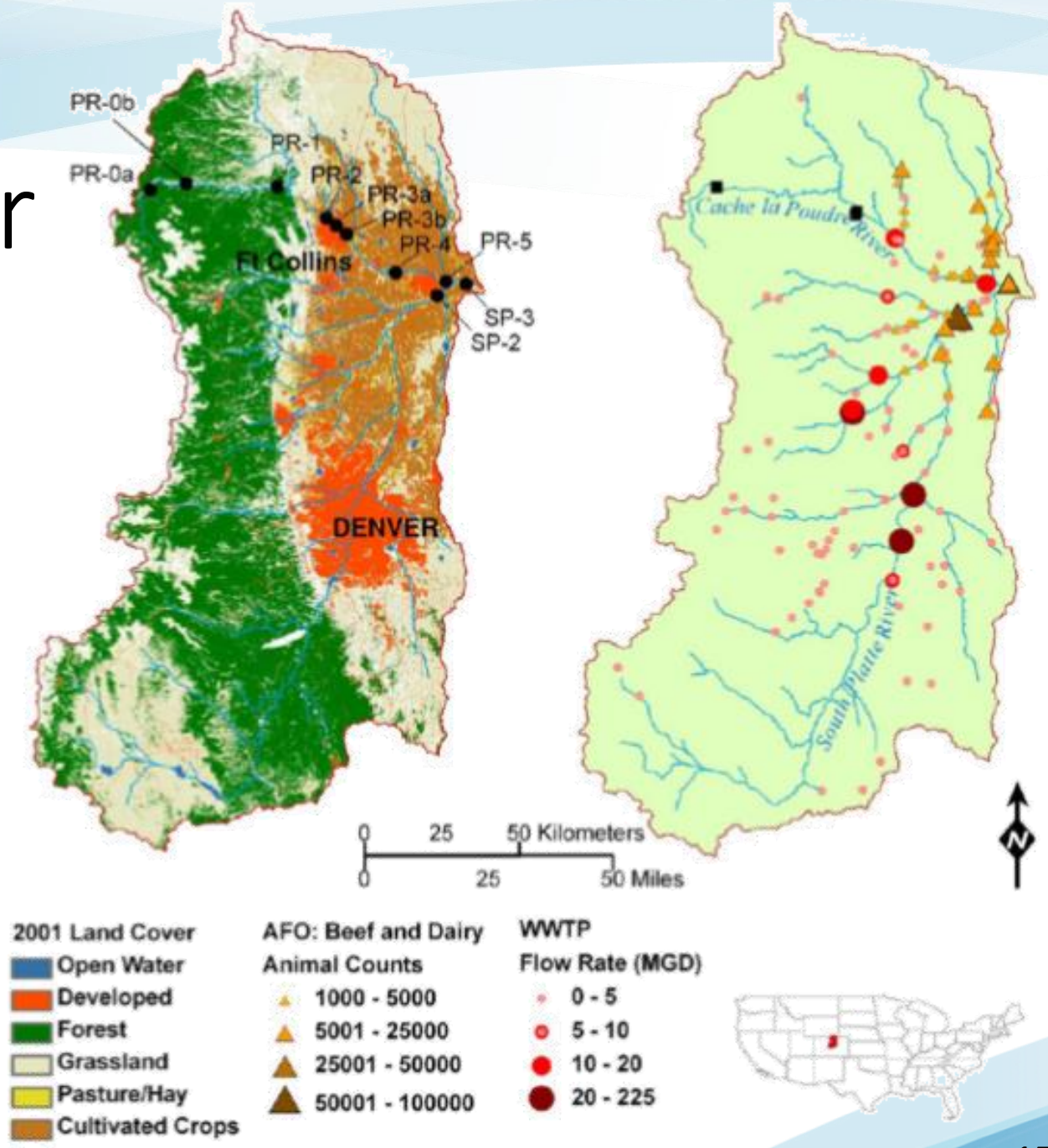
1,000 year flood: Cache la Poudre River, Colorado, USA

Hurricane Maria: Puerto Rico, USA

Hurricane Harvey: Houston, Texas, USA

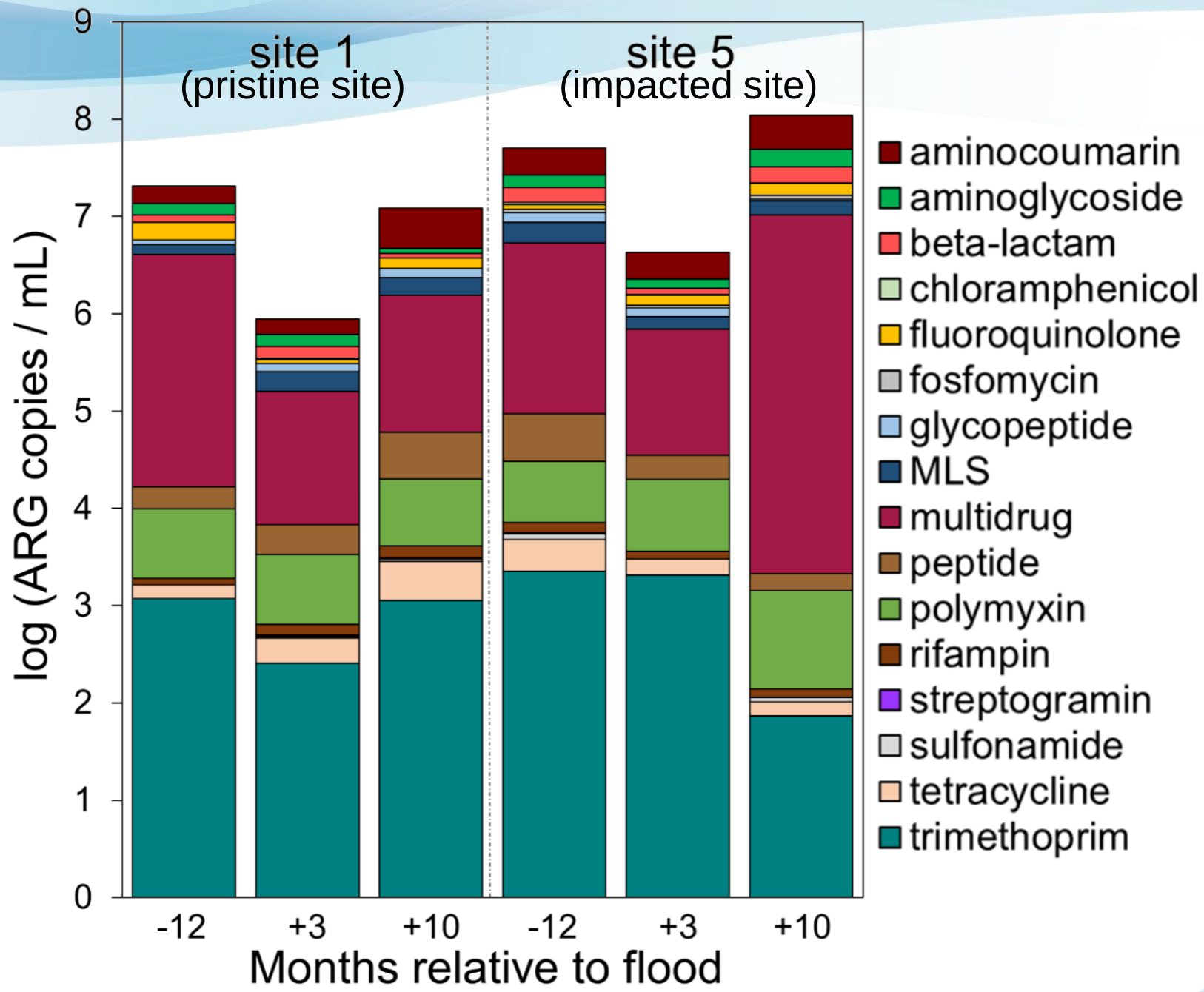
Recurrent Localized Flooding: Stroubles Creek, Virginia, USA

Cache La Poudre River Fort Collins, CO

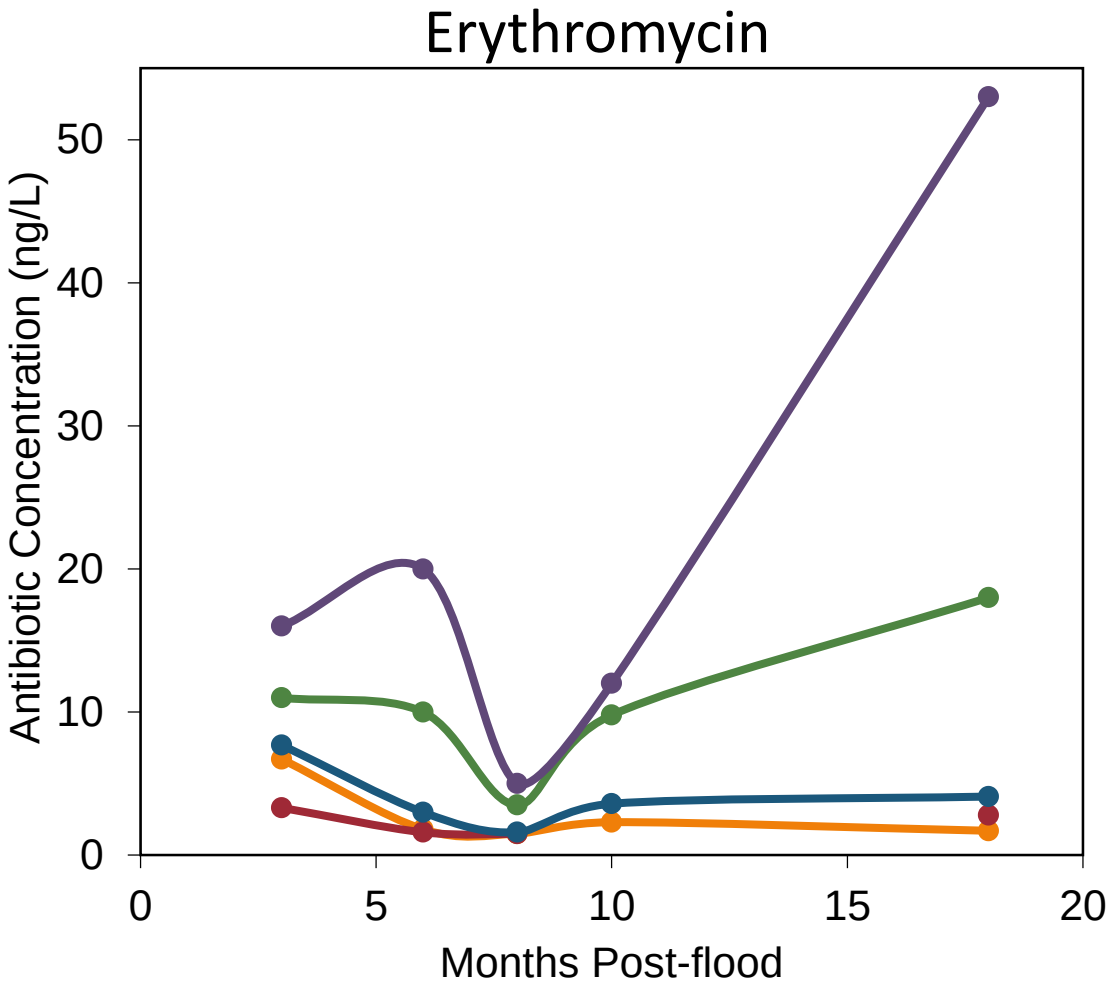


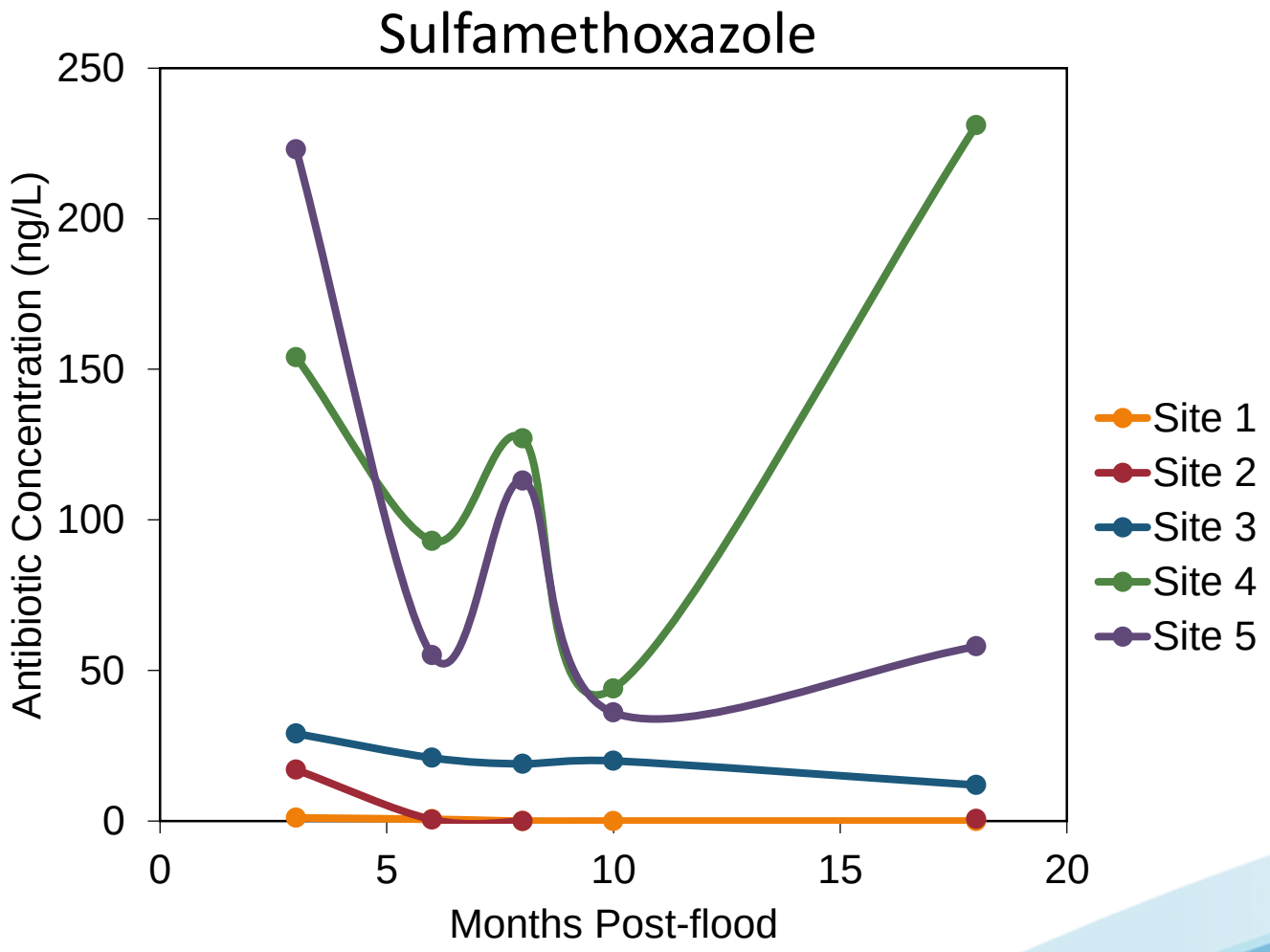
Pruden et al, *Environ Sci & Technol*, 2012

Garner et al., 2016, *Scientific Reports*



Antibiotics





Potential selection by antibiotics and metals

Antibiotics	*sul*1		*sul*2		*tet*(O)		*tet*(W)		*erm*F	
	sed	wat	sed	wat	sed	wat	sed	wat	sed	wat
ATC	0.26	-0.03	0.16	0.04	0.11	**0.41**	0.25	0.32	0.04	0.05
AZI	**0.50**	0.08	0.30	0.30	**0.51**	**0.38**	**0.40**	**0.35**	**0.35**	0.27
CLA	**0.41**	-0.10	0.24	**0.38**	**0.45**	**0.50**	0.33	**0.46**	0.32	**0.40**
CTC	0.13	-0.05	0.08	-0.07	-0.03	0.30	0.20	0.11	-0.06	0.17
DOX	0.24	-0.28	0.28	-0.28	0.33	-0.26	0.30	-0.26	0.30	-0.27
ERY	**0.39**	-0.11	0.06	**0.36**	**0.51**	**0.58**	**0.47**	**0.46**	0.25	**0.42**
ETC	-0.01	-0.28	-0.08	-0.11	-0.02	0.17	-0.05	0.13	-0.15	-0.19
OTC	0.24	0.32	0.10	0.12	0.15	0.01	0.26	0.00	0.22	0.10
SDM	0.28	0.09	0.06	0.15	-0.02	-0.01	-0.05	0.01	-0.15	0.01
SMX	**0.50**	-0.09	0.24	**0.40**	**0.44**	**0.49**	**0.39**	**0.45**	**0.37**	**0.56**
SMZ	0.28	-0.11	-0.04	0.14	0.13	**0.46**	0.00	**0.36**	0.08	0.34
SPD	**0.46**	0.19	0.17	0.29	0.15	0.15	0.07	0.29	0.04	0.25
TC	0.11	-0.05	0.11	0.21	0.25	**0.58**	0.16	**0.47**	0.13	0.26
TYL	0.30	0.07	**0.40**	0.24	**0.47**	0.19	**0.52**	0.26	**0.48**	0.07

Bold indicates significance at α=0.05

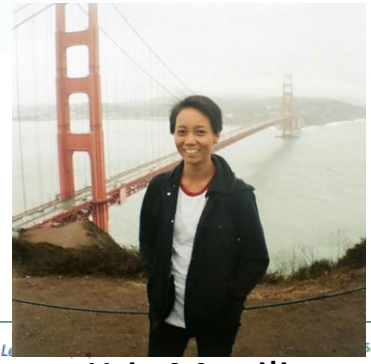
Garner et al., 2016, *Scientific Reports*

Correlations noted between ARGs and antibiotics:

- Macrolides (AZI, CLA, ERY, TYL) – *sul*1, *sul*2, *tet*(O), *tet*(W), *erm*F
- Sulfonamides (SMX, SMZ) – *sul*1, *sul*2, *tet*(O), *tet*(W), *erm*F
- Tetracycline (TC) – *tet*(O), *tet*(W)

Hurricane Harvey: Houston, Texas

- Sampling Campaign Targeted:
  - Soil collected from:
    - Parks (Surface Soil)
    - Backyards (Surface Soil)
    - Parks (Deep Soil)
  - Environments sampled:
    - Indoor
    - Street
    - Bayou



Kris Mapili

Lauren Stadler

Environmental Science & Technology Letters

Cite This: Environ. Sci. Technol. Le

Elevated Levels of Pathogenic Indicator Bacteria and Antibiotic Resistance Genes after Hurricane Harvey's Flooding in Houston

Pingfeng Yu,[†] Avery Zaleski,[†] Qilin Li,[†] Ya He,[†] Kris Mapili,[‡] Amy Pruden,[‡] Pedro J. J. Alvarez,[†] and Lauren B. Stadler*[,†]

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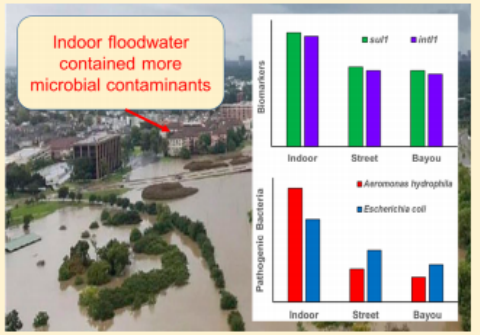
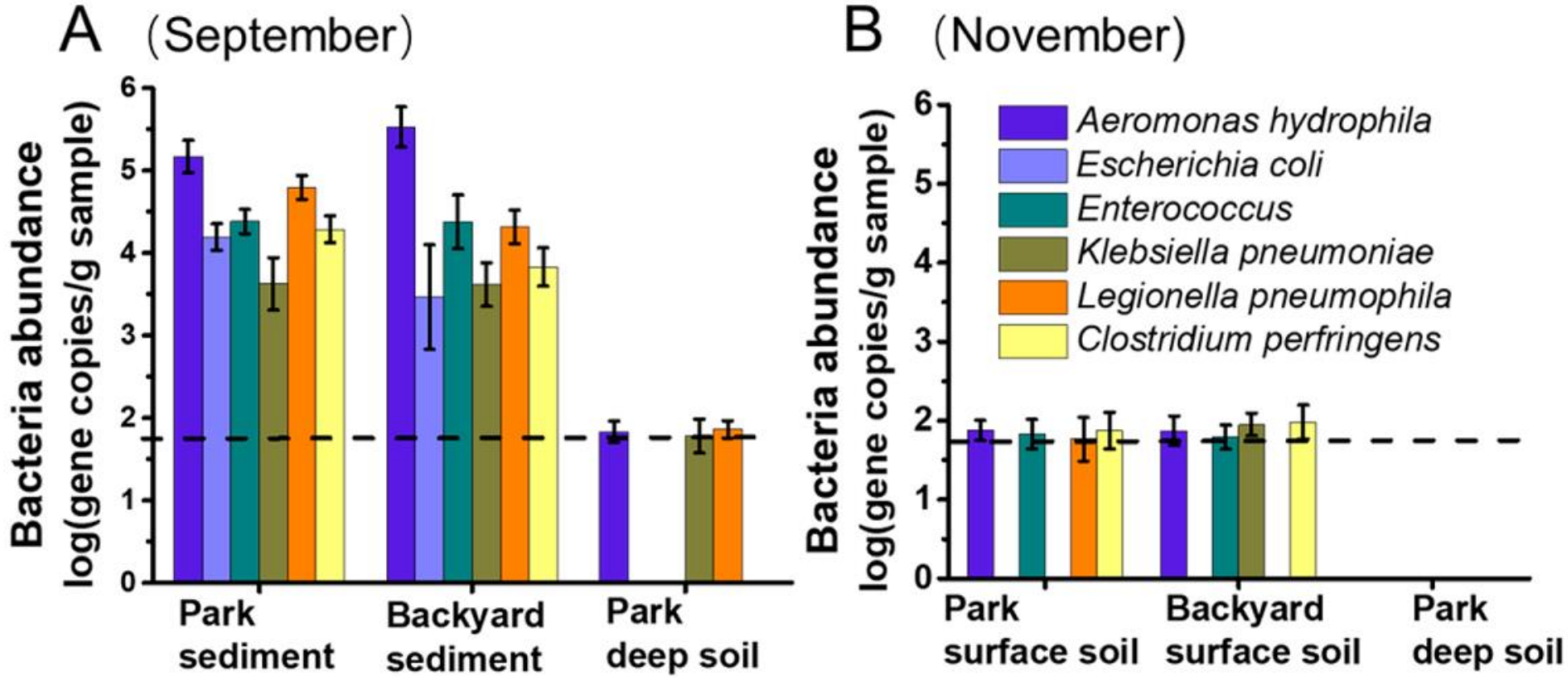
Supporting Information

ABSTRACT: Urban flooding can dramatically affect the local microbial landscape and increase the risk of waterborne infection in flooded areas. Hurricane Harvey, the most destructive hurricane since Katrina in 2005, damaged more than 100000 homes in Houston and flooded numerous wastewater treatment plants. Here we surveyed microbial communities in floodwater inside and outside residences, bayou water, and residual bayou sediment collected immediately postflood. Levels of *Escherichia coli*, a fecal indicator organism, were elevated in bayou water samples as compared to historical levels, as were relative abundances of key indicator genes of anthropogenic sources of antibiotic resistance (*sul*1/16S rRNA and *intI*1/16S rRNA) based on 6 month postflood monitoring. Quantitative polymerase chain reaction measurements showed that gene markers corresponding to putative pathogenic bacteria were more abundant in indoor floodwater than in street floodwater and bayou water. Higher abundances of 16S rRNA and *sul*1 genes were also observed in indoor stagnant waters. Sediments mobilized by floodwater exhibited an increased abundance of putative pathogens postflood in both residential areas and public parks. Overall, this study demonstrates that extreme flooding can increase the level of exposure to pathogens and associated risks.

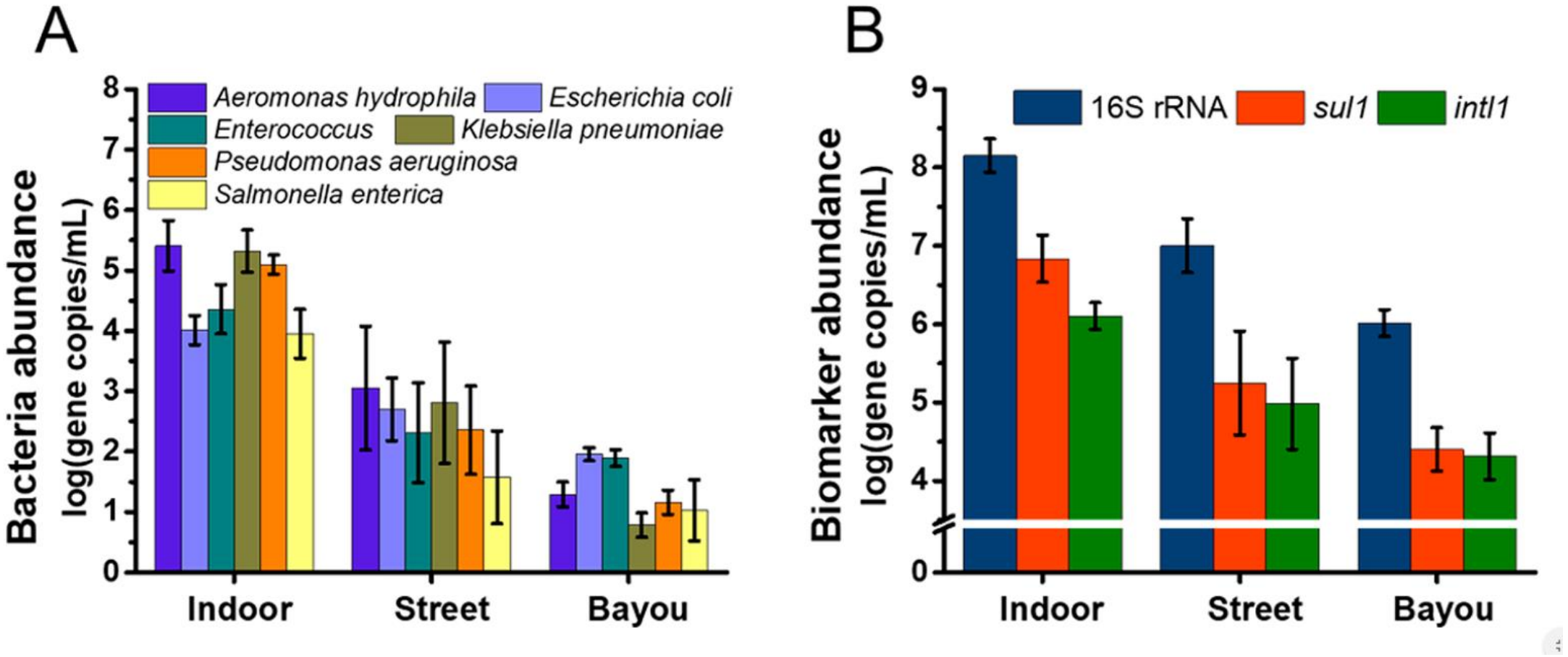


Hurricane Harvey: Houston, Texas



Yu et al., *Environ. Sci. Technol. Lett.* 2018; 5, 8, 481-486

Hurricane Harvey



Yu et al., *Environ. Sci. Technol. Lett.* 2018; 5, 8, 481-486

Hurricane Maria: Puerto Rico

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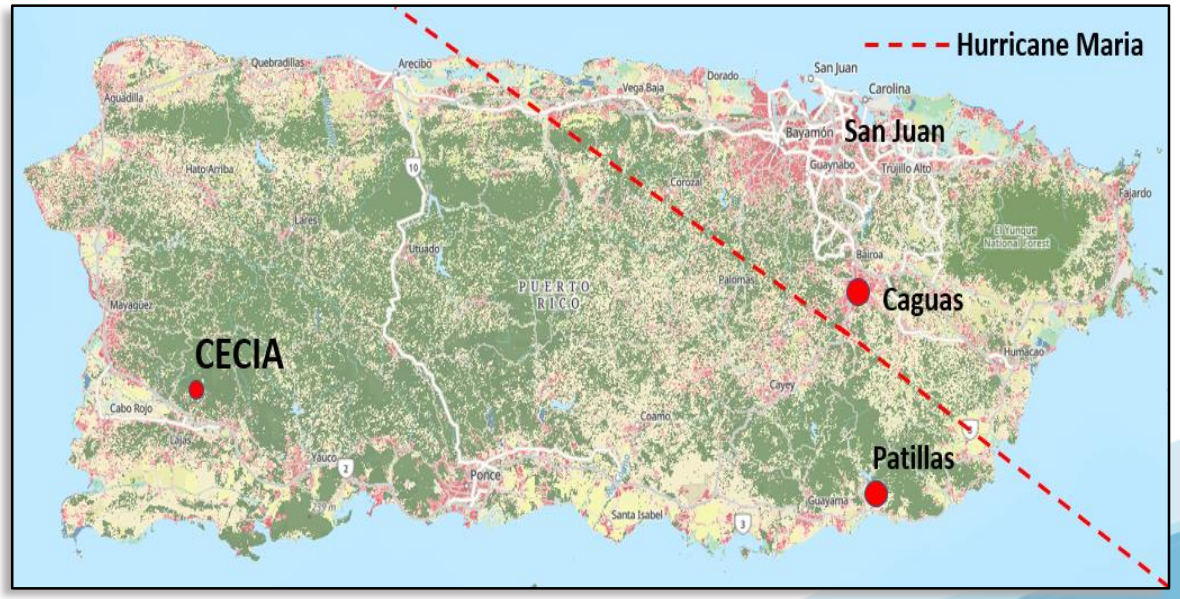
- September 2017 (Category 4 Storm)
- Impacts to Puerto Rico
  - severe flooding
  - massive energy outages
  - interruptions in water and wastewater treatment and delivery
- Challenges in providing treated drinking water to small communities were intensified due to damage incurred to the existing systems, limited funding, and the continuing lack of electricity

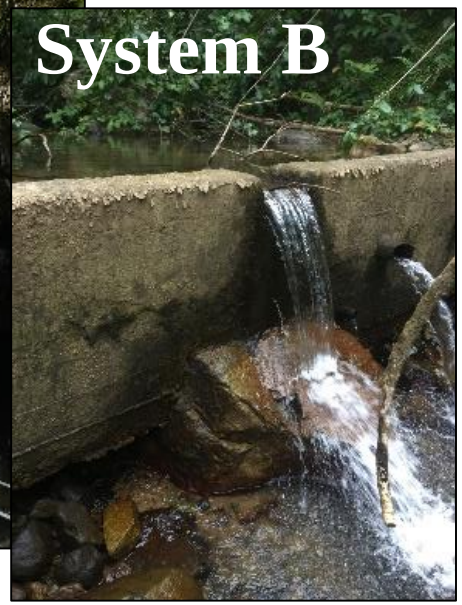
Ishi Keenum

Benjamin Davis

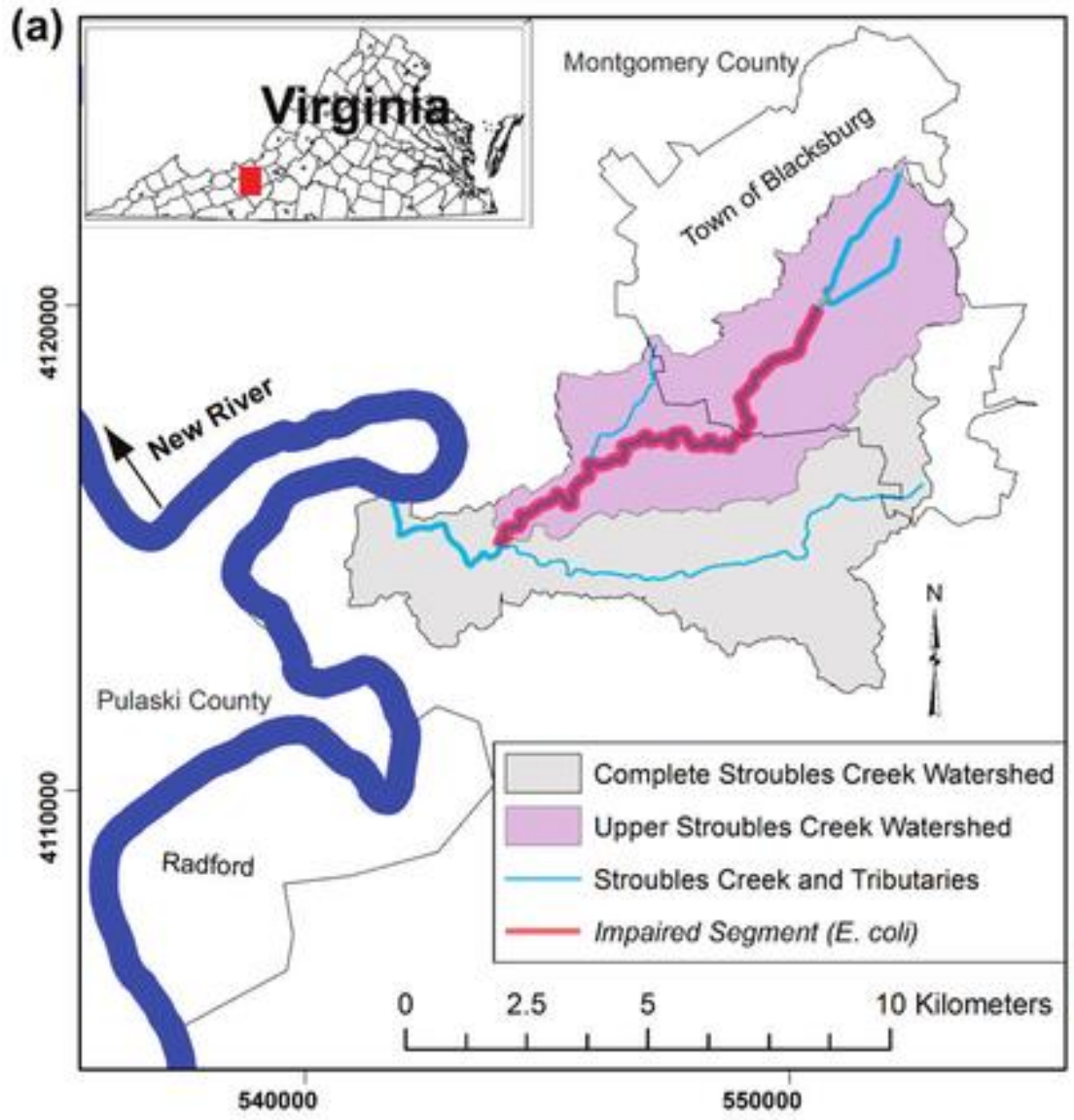


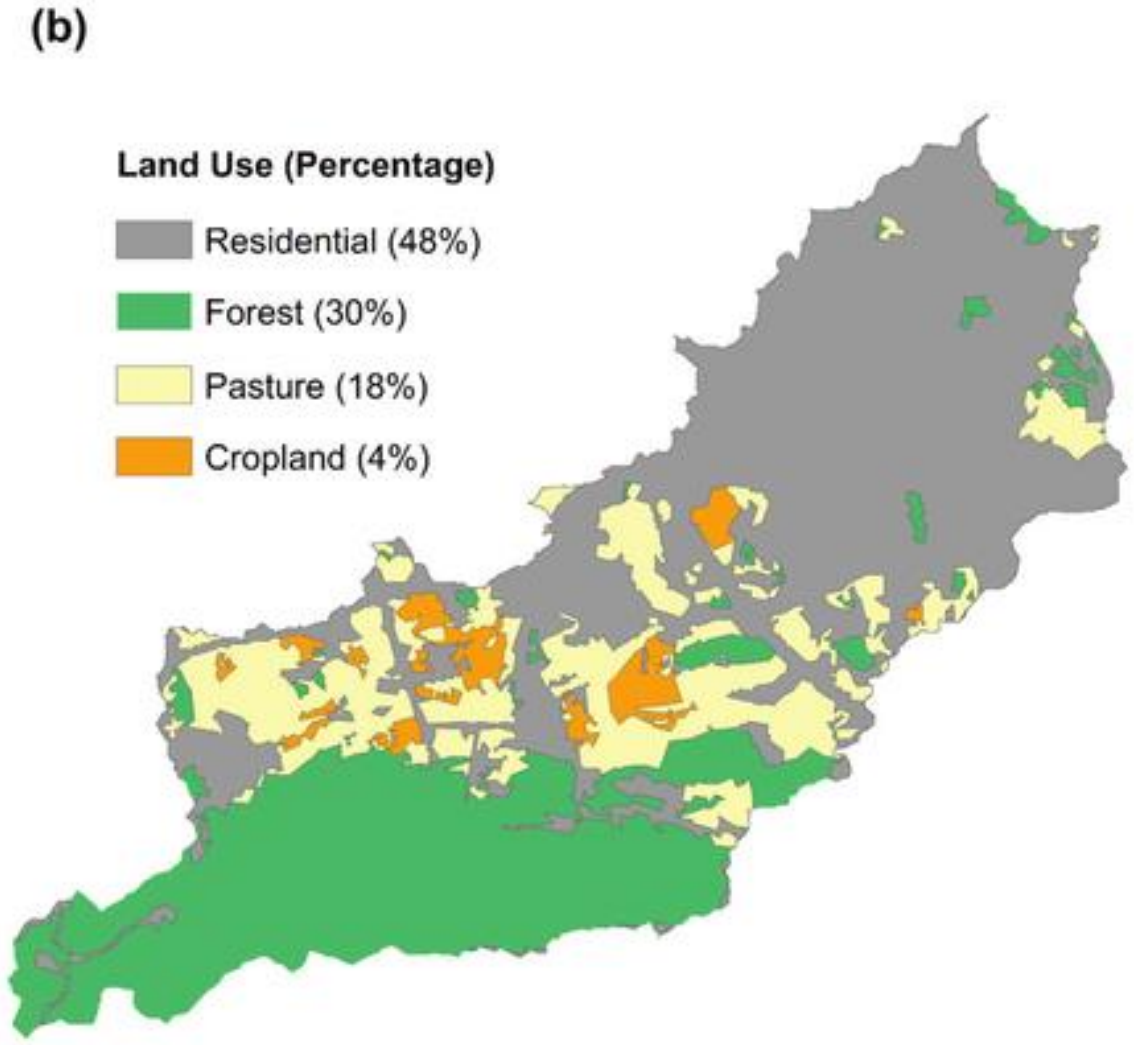
Condition of Rural Puerto Rico Drinking Water Systems

- Damage included fallen trees, disrupted dams, and excessive foliage/sediment buildup

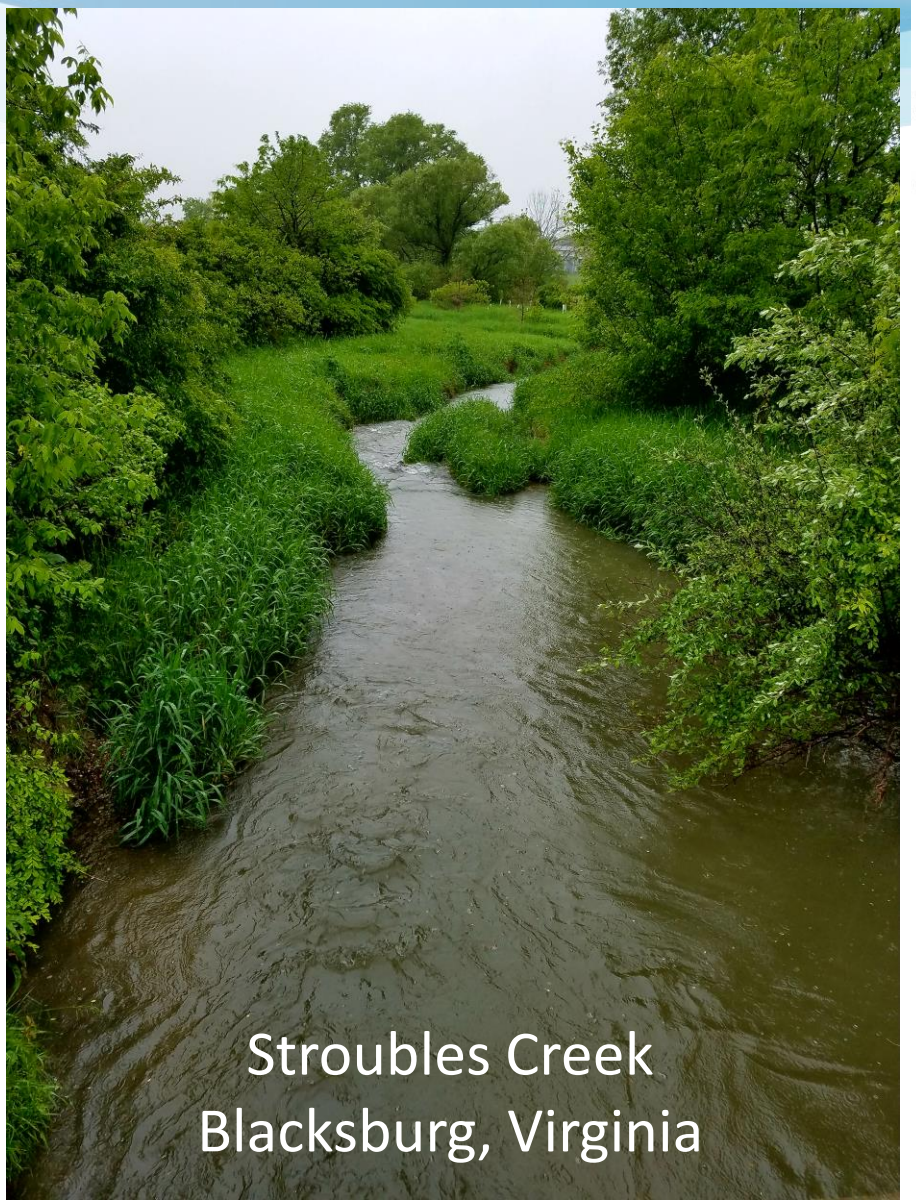


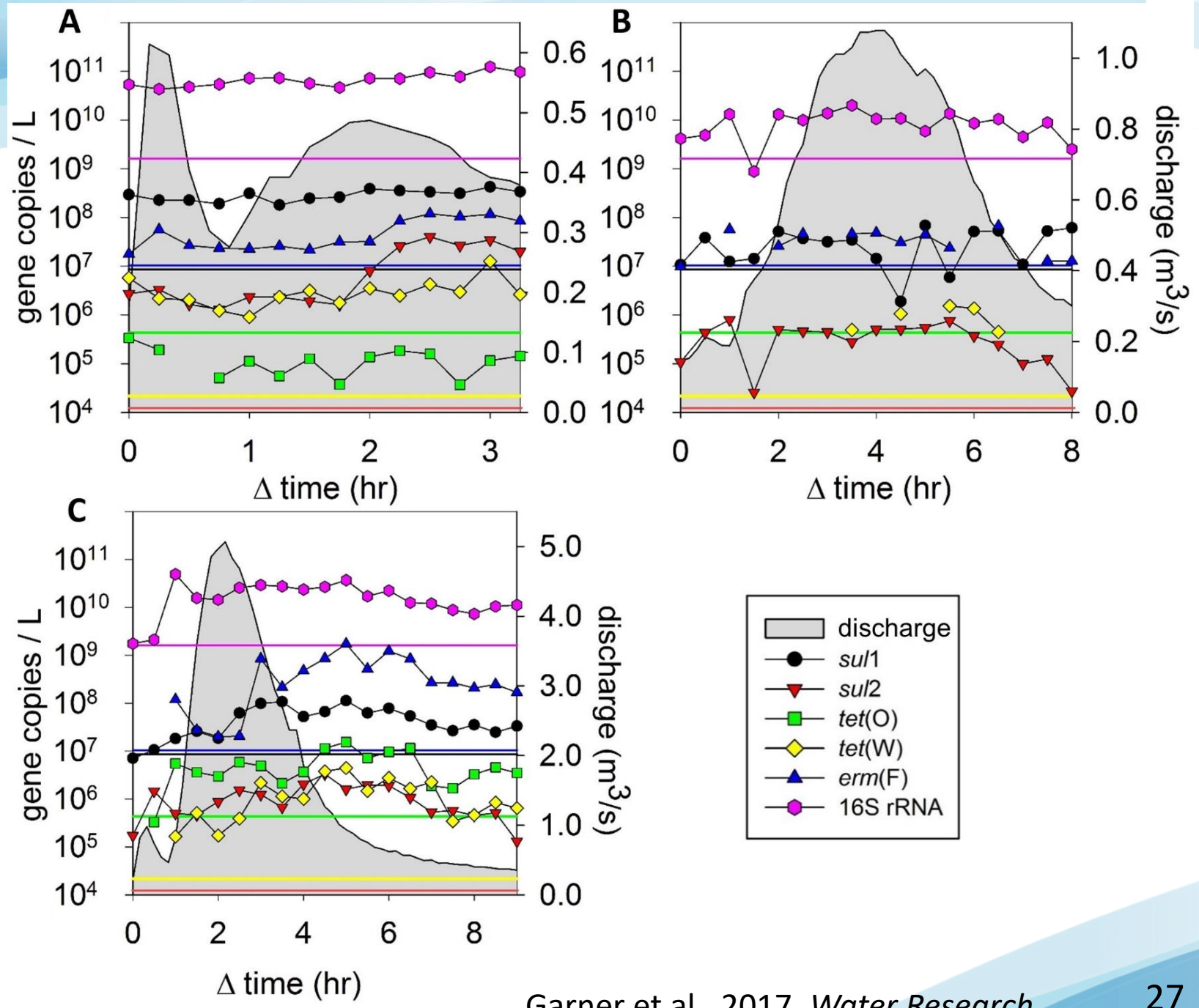
Stroubles Creek, Blacksburg, VA





Liao et al, *J. Environ. Qual*. 2015

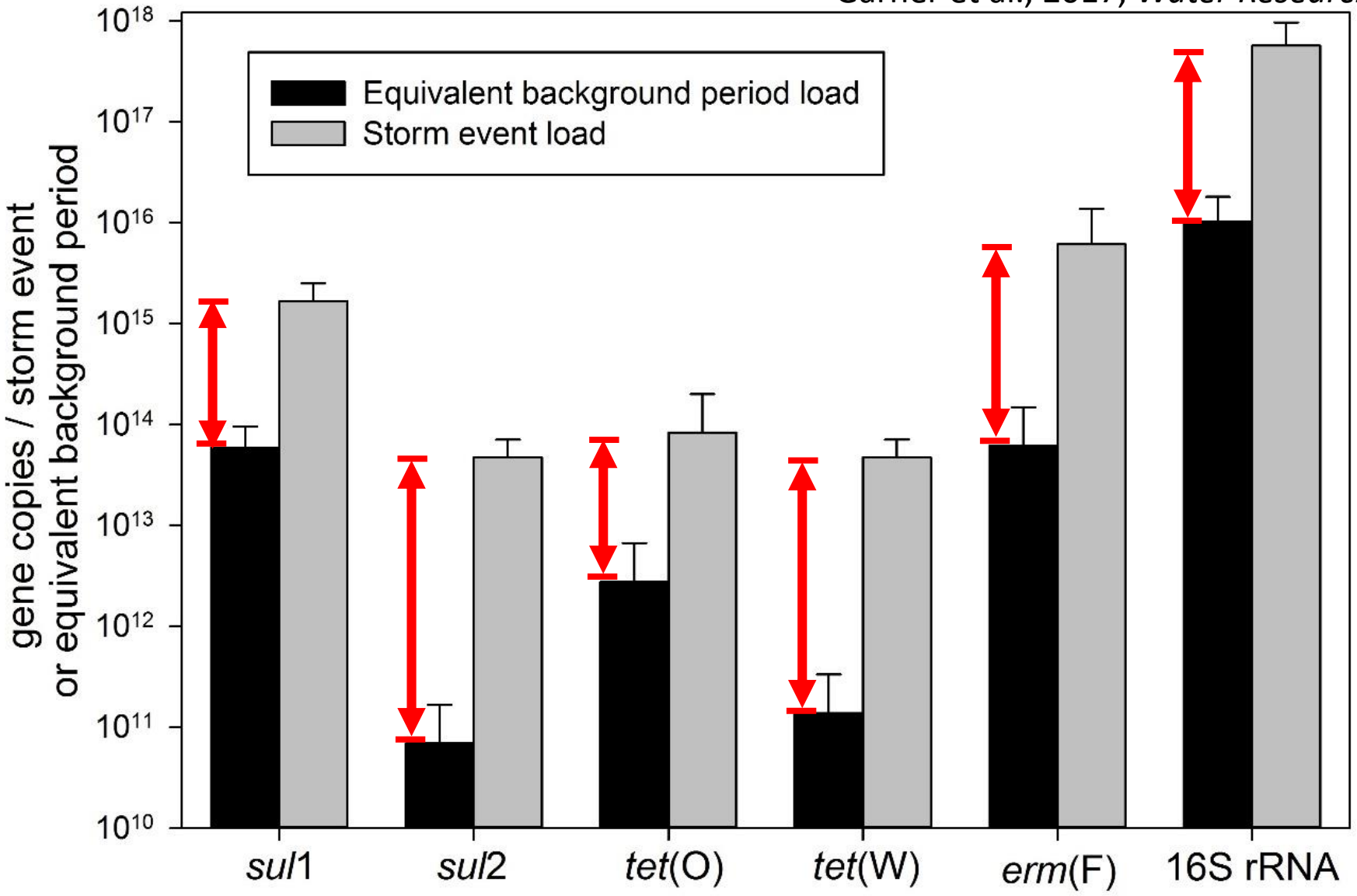




Garner et al., 2017, *Water Research*

Storm Loading of ARGs

Garner et al., 2017, *Water Research*



ARGs vs. fecal indicator bacteria and physicochemical water quality

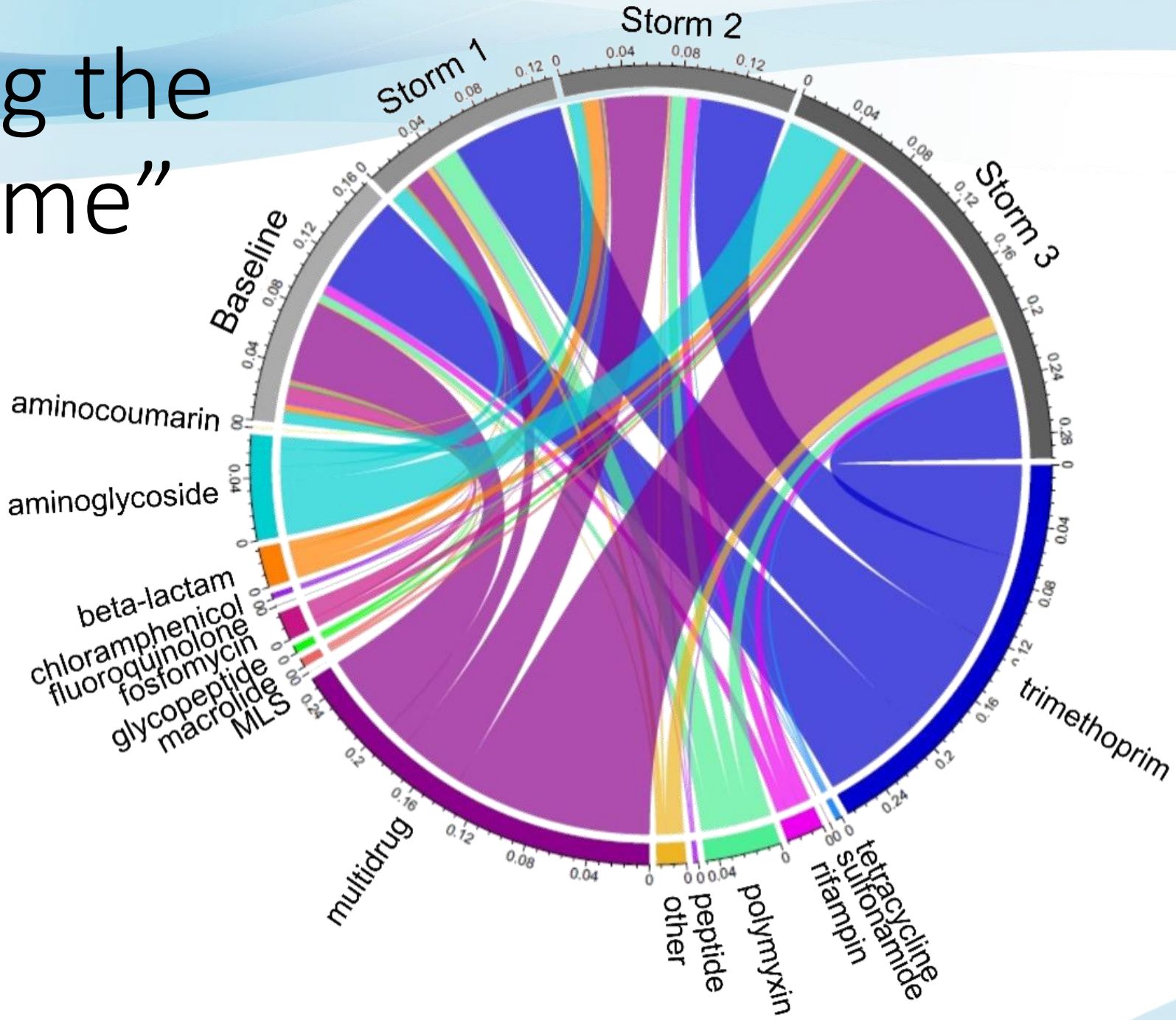
	E. coli	enterococci	temperature	turbidity	dissolved oxygen	conductivity	pH
*sul*1	0.123	0.167	**0.279***	**0.392***	−0.188	−0.206	**−0.285***
*sul*2	0.165	**0.244***	**0.327***	**0.467***	−0.221	−0.165	**−0.251***
tet(O)	**0.363***	**0.522***	**0.446***	**0.753***	**−0.397***	**0.316***	−0.063
tet(W)	**0.330***	**0.321***	**0.312***	**0.542***	**−0.266***	−0.138	**−0.274***
erm(F)	0.150	**0.314***	**0.324***	**0.619***	**−0.508***	**0.271***	**−0.339***

*Significant correlation coefficients are indicated in bold

Fecal indicator bacteria are a poor indicator of overall ARG contamination

Garner et al., 2017, *Water Research*

Exploring the "Resistome"



Conclusions

- Flooding leads to a variety of environmental and human health impacts, including toxic chemical exposures and waterborne disease
- Antibiotic resistance among waterborne diseases leads to high treatment costs and higher morbidity and mortality
- Surveillance strategies are needed to monitor antibiotic resistance both during flooding and in typical conditions
- Risk assessment frameworks are needed to better relate waterborne antibiotic resistant bacteria to human health risk

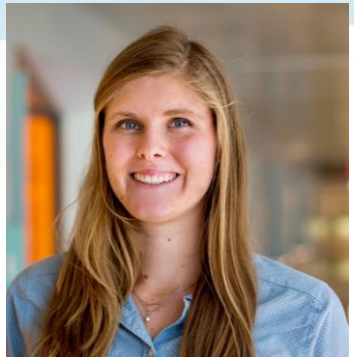
THE Water Research FOUNDATION

WRF Project #4813

Acknowledgements

Amy Pruden

Kris Mapili



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