UNC INSTITUTE OF MARINE SCIENCES

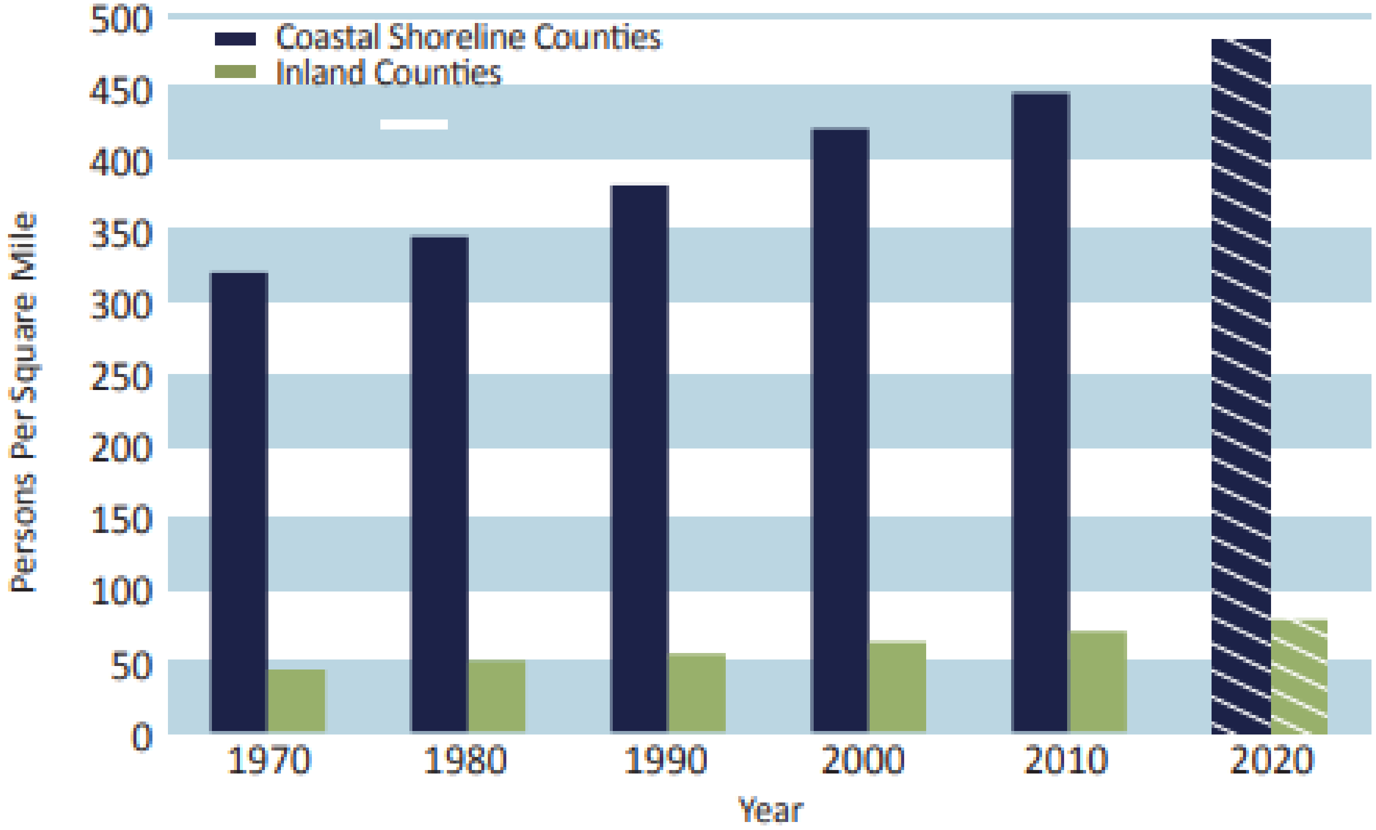
Using molecular approaches for coastal municipal stormwater and wastewater infrastructure based decision-making

Rachel T. Noble

26 April 2021

NC Beach, Inlet, and Waterway Association Spring Meeting

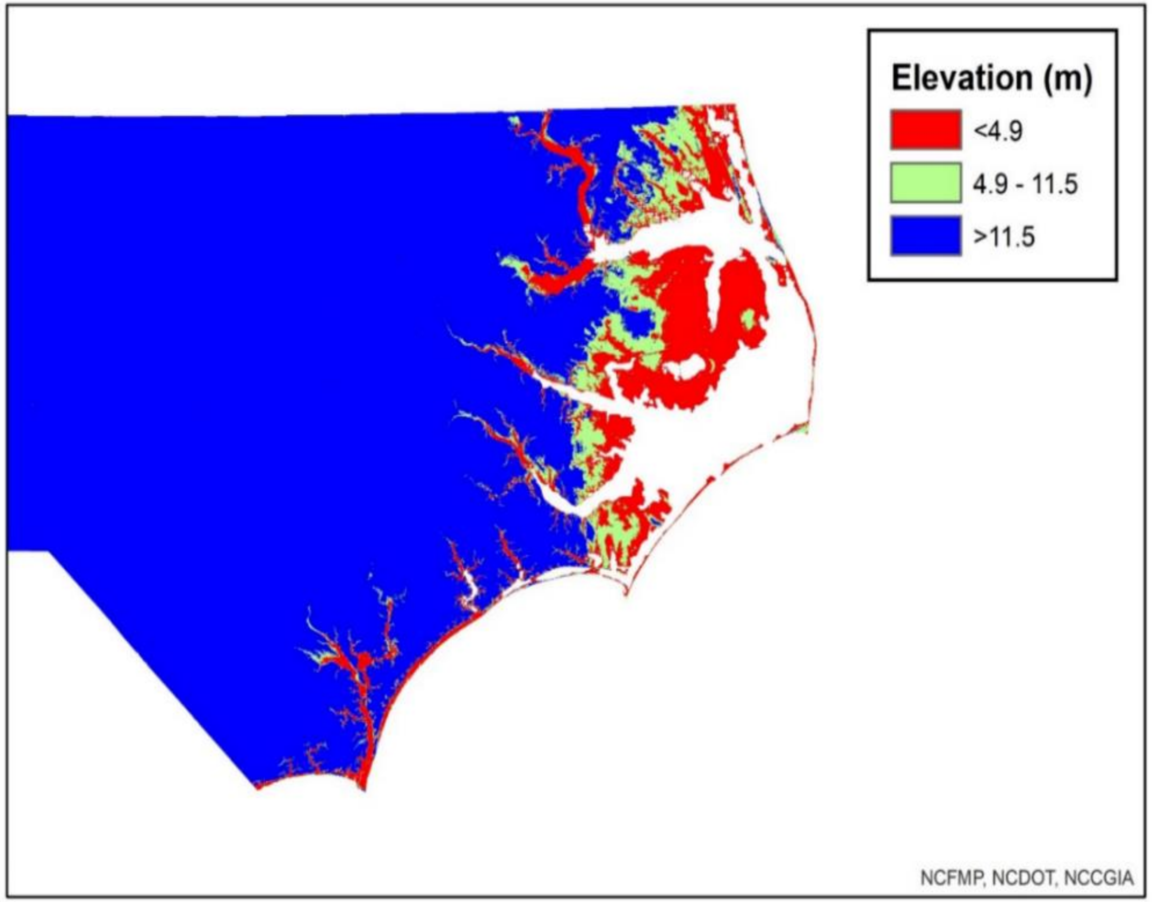
Scope of the Problem



(NOAA, 2013)

- Urbanization in coastal watersheds (Freeman et al., 2019)
- Aging infrastructure with increasing demand (ASCE, 2017)
- More frequent and intense storm events (Knutson et al., 2020)

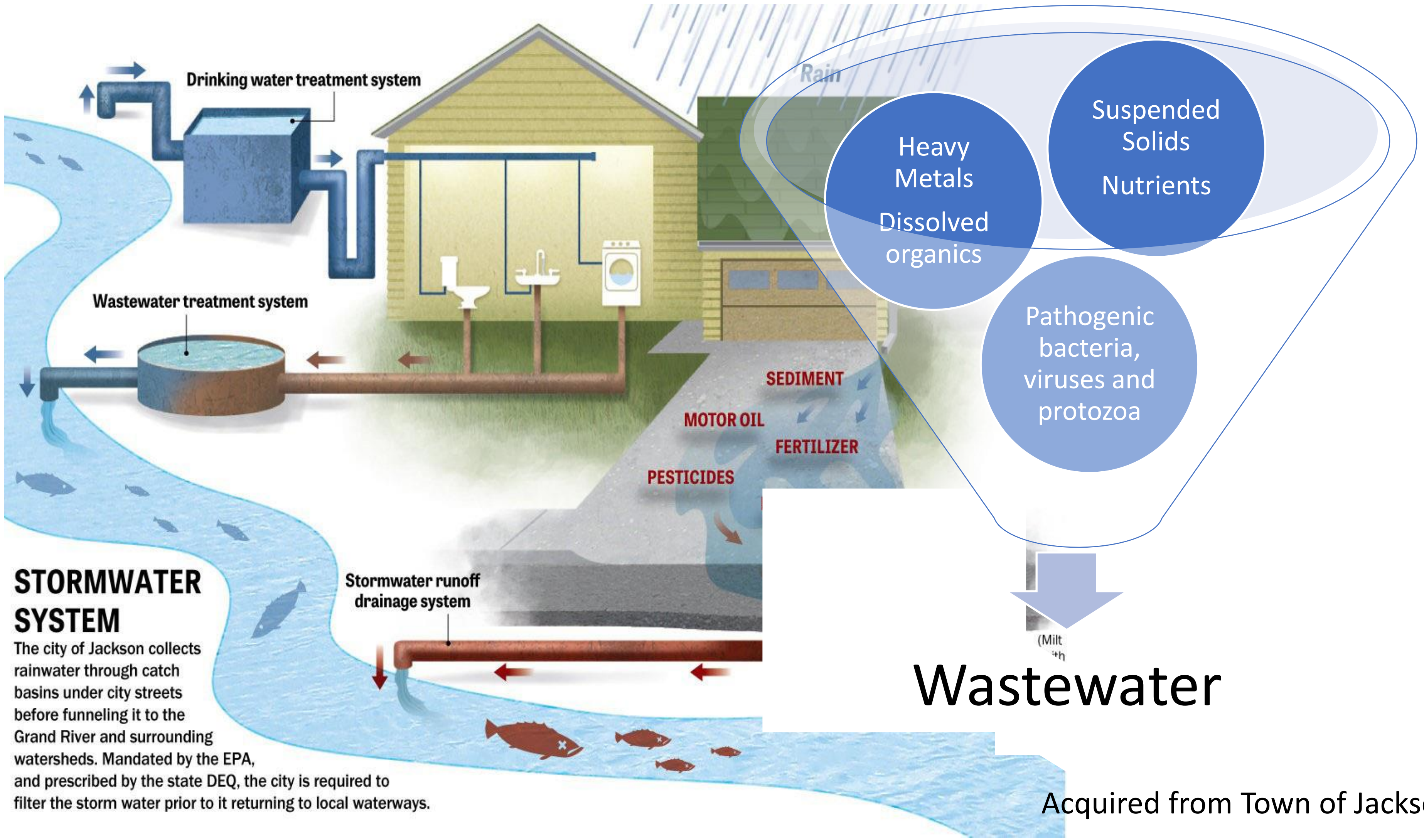
NC Coastal Plain



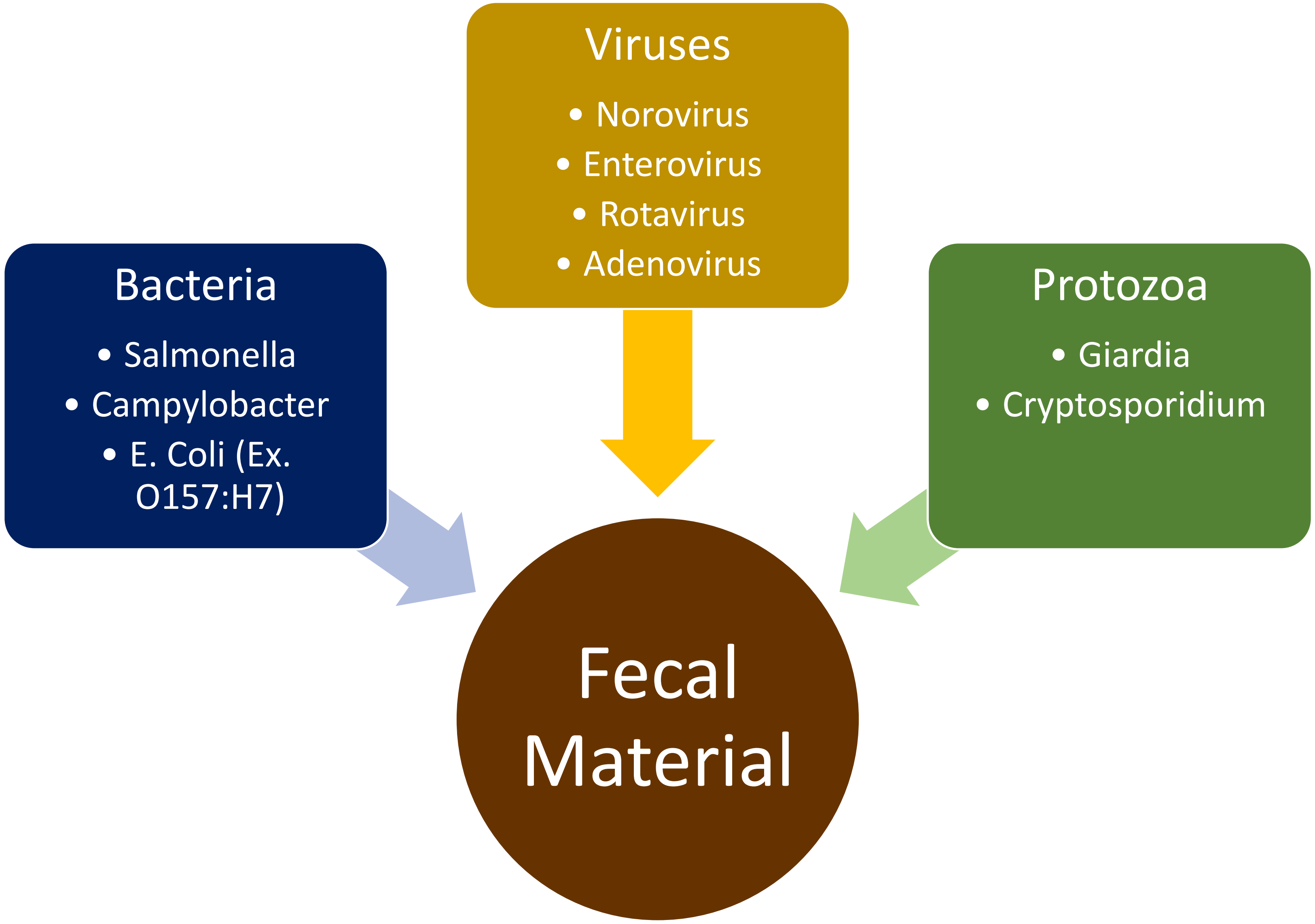
Digital Elevation Model (DEM) Depicting Elevation in Coastal, Eastern NC

- NC 3rd largest low-lying region in the US (Poulter et al., 2009)
- Sea level up 0.28 meters higher than in 1950 (SeaLevelRise.org, 2020)
- Coastal region expected to grow 26% within decade (NC Office of State Budget and Management, 2015)

Wastewater vs. Stormwater

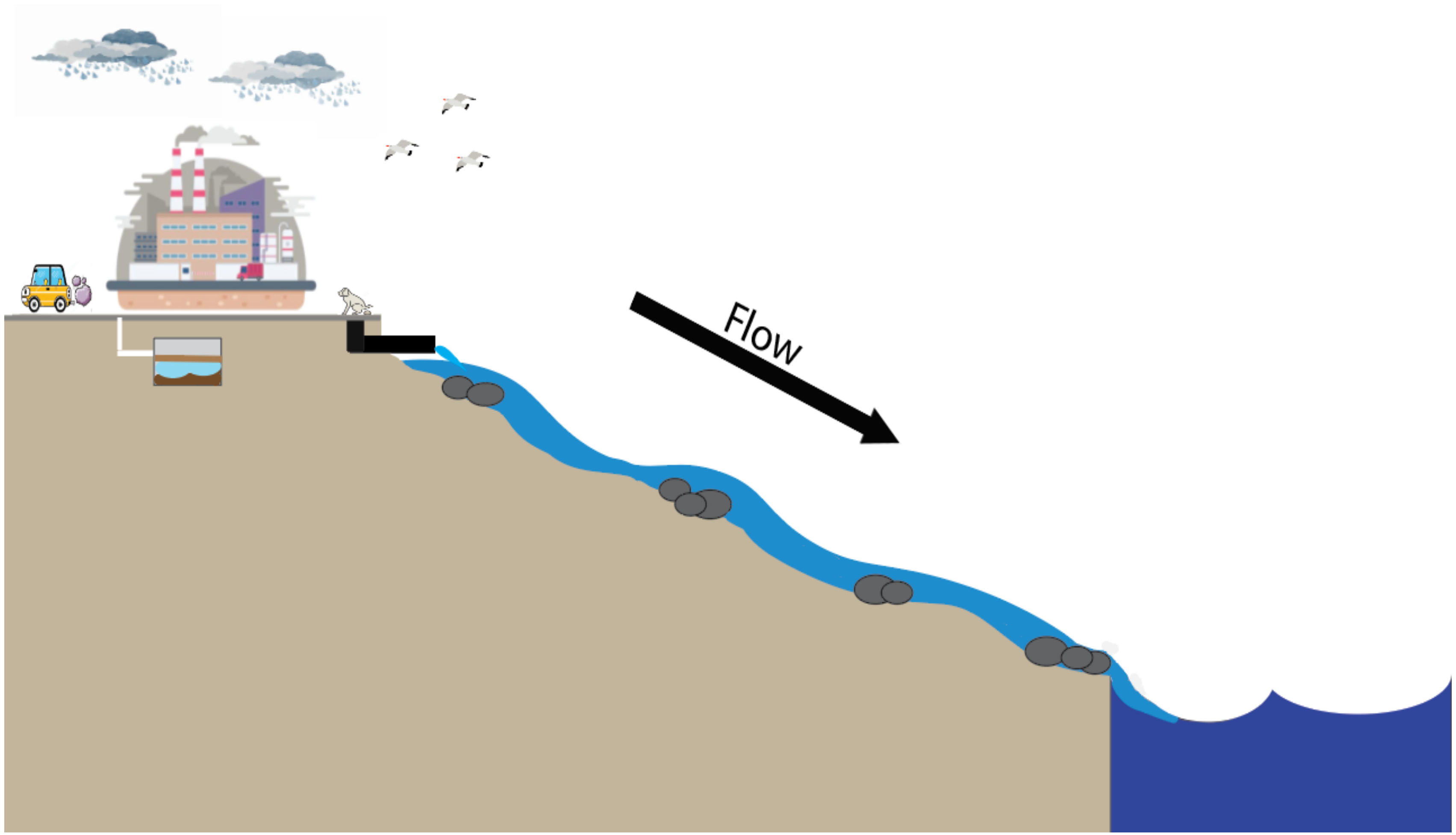


Acquired from Town of Jackson, MI website

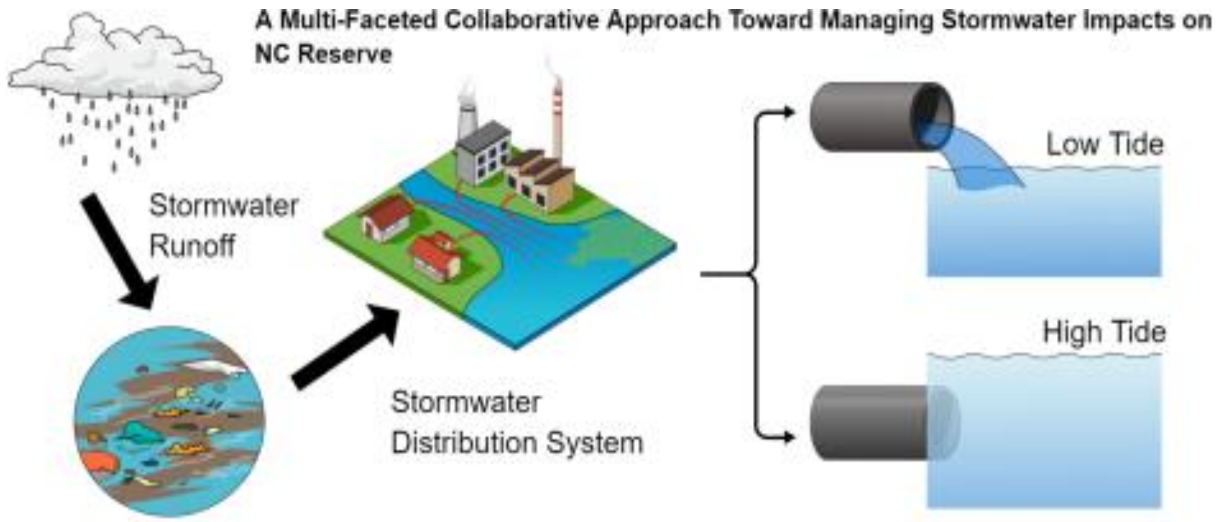

Viruses
• Norovirus
• Enterovirus
• Rotavirus
• Adenovirus
Bacteria
• Salmonella
• Campylobacter
• E. Coli (Ex. O157:H7)
Protozoa
• Giardia
• Cryptosporidium
Fecal Material

Public Health & Economic Significance

- Exposure linked with adverse health effects
  - Increased incidence of gastrointestinal illness (Arnold et al., 2017)
- Estimated annual economic burden of $2.9 billion (DeFlorio-Barker et al., 2018)
- USEPA Regulatory Framework



(Adapted from Palmer et al., 2014)



Integrating Culture and Molecular Quantification of Microbial Contaminants into a Predictive Modeling Framework in a Low-Lying, Tidally-Influenced Coastal Watershed

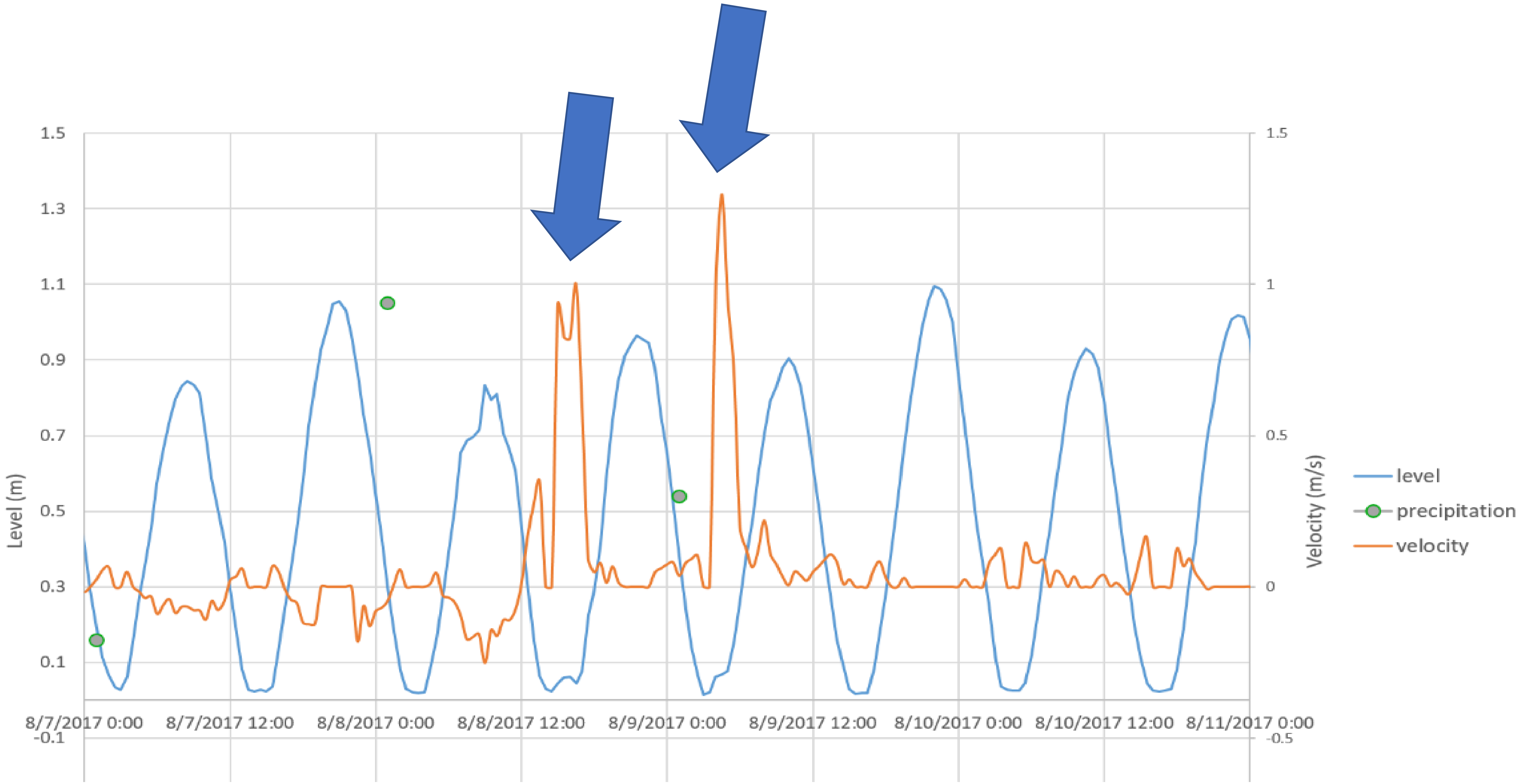
M Price, AD Blackwood, RT Noble, 2021 in review

Background

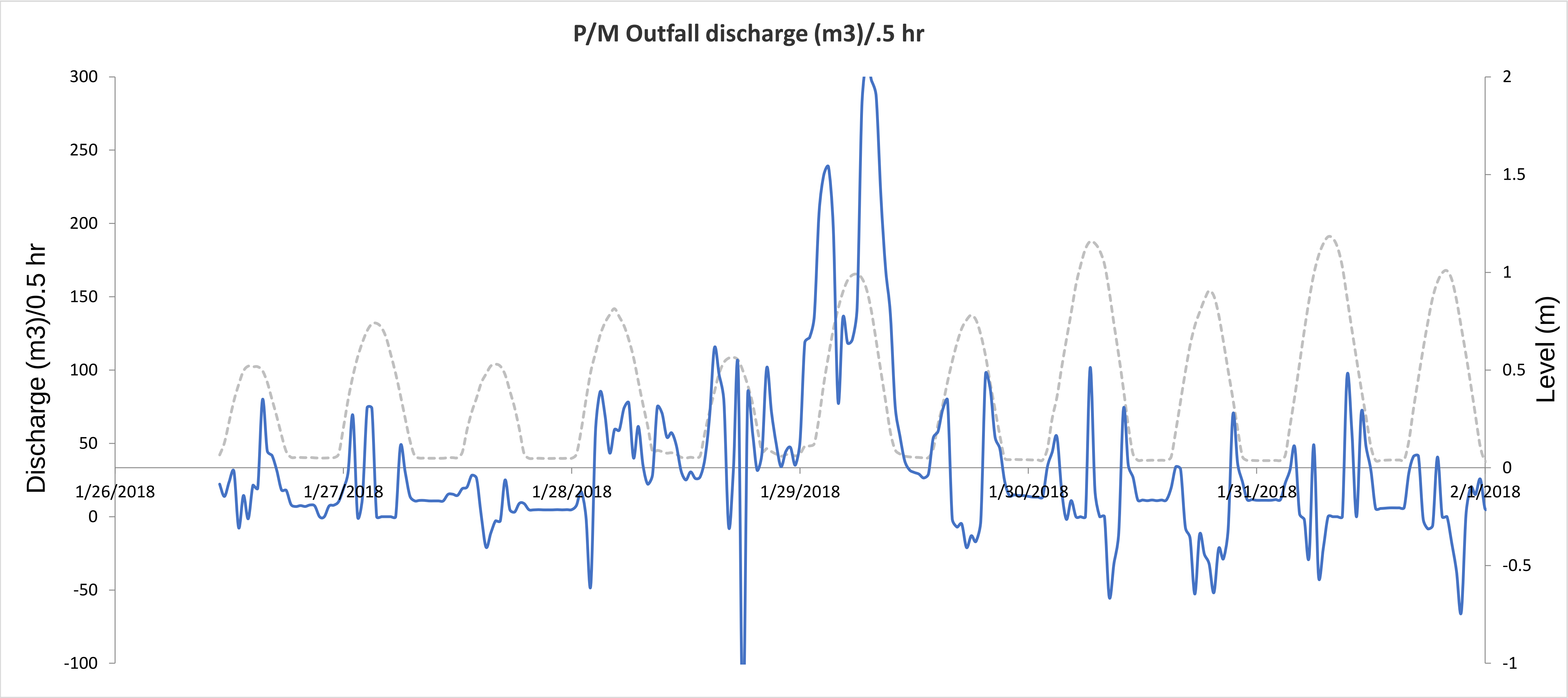
- Stormwater dynamics in coastal NC vary (Hart et al., 2020)
  - Hydrological and meteorological factors vary on a local scale (Ex. regional weather patterns)
- Low-lying coastal terrain with minimal topographic slope (NOAA, 2020)
- Semi-diurnal tides with moderate range (King Tides, 2020)
- Proximity to Rachel Carson Reserve (RCR)
  - Within NC Coastal and National Estuarine Research Reserve Systems (NC NERRS)

Study Site: Town of Beaufort (ToB), NC

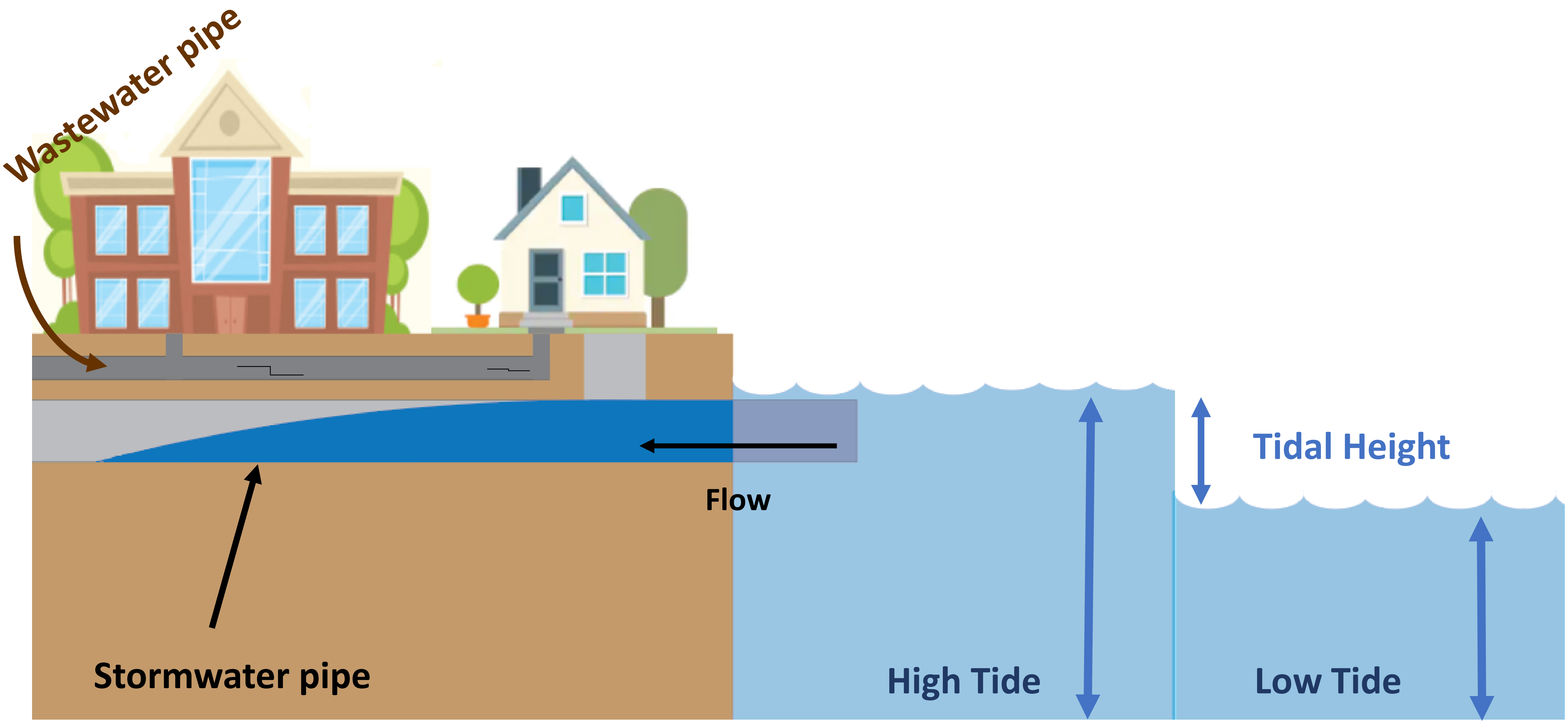
In a Perfect World



Reality



P/M Outfall discharge (m3)/.5 hr
Discharge (m3)/0.5 hr
Level (m)
300
250
200
150
100
50
0
-50
-100
2
1.5
1
0.5
0
-0.5
-1
1/26/2018
1/27/2018
1/28/2018
1/29/2018
1/30/2018
1/31/2018
2/1/2018



Wastewater pipe
Tidal Height
Flow
Stormwater pipe
High Tide
Low Tide

1. Determine quantity and sources of stormwater-related contaminants to Taylor's Creek and Rachel Carson Reserve (RCR)

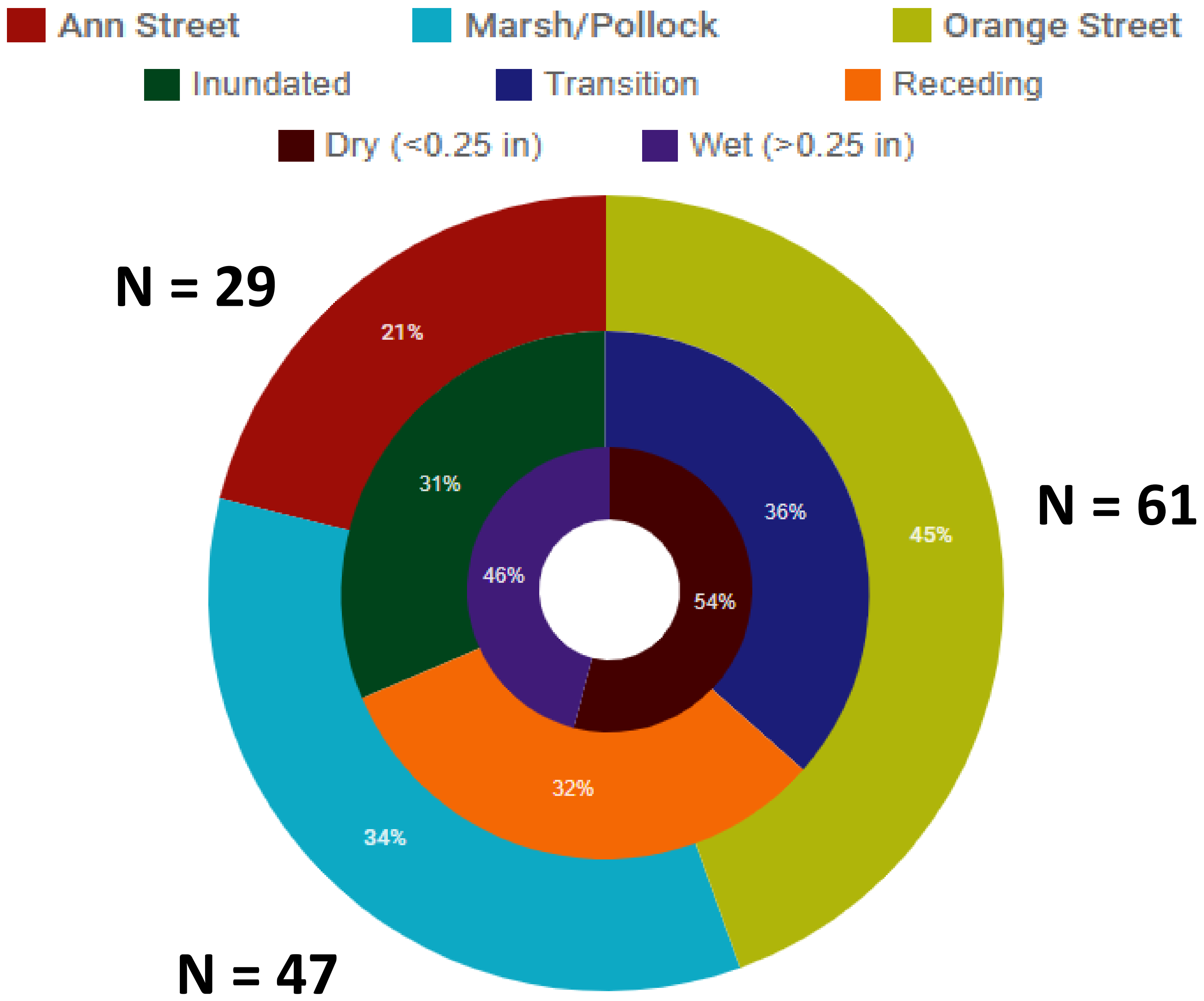
- Previous research conducted showing significant levels of human-associated fecal contamination (Hart et al., 2020)
- Differences exist between bacterial loading between WWTP-impacted waters and waters with diffuse sources of pollution (US EPA, 2012)

2. Use predictive modeling tools to understand drivers of fecal contaminant delivery

- Characterize tidal phase in a manner never done before within an estuarine, receiving water system
- Determine microbial delivery patterns in context of tidal cycle and other parameters

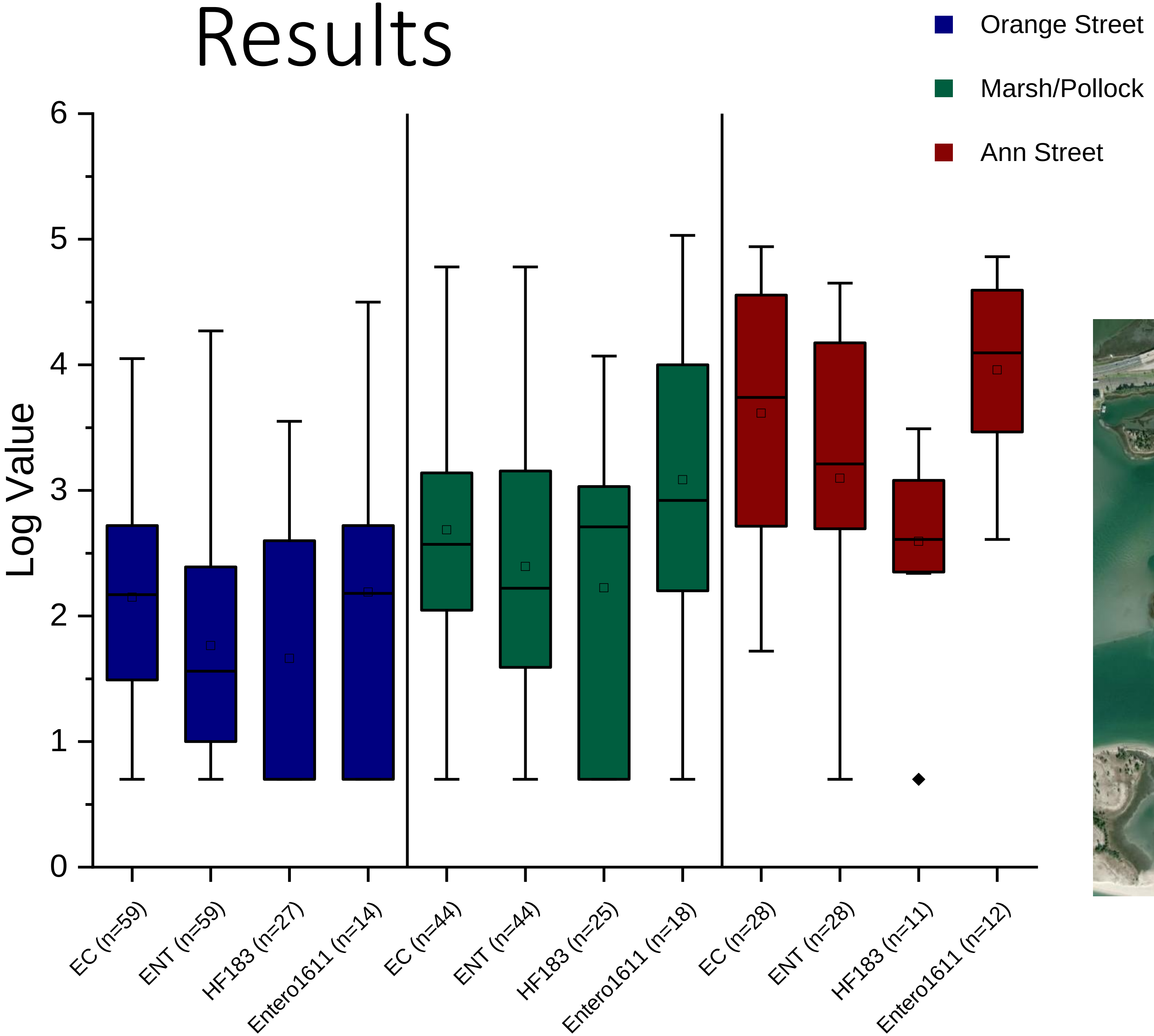
Methods

- Samples were collected during both storm (>0.25 in) and ambient conditions from July 2017 to June 2018.
- Classified into tidal categories by distance of sample collection from nearest high tide.
  - Inundated (<2 h), Transition (2-4 h) and Receding (>4 h)

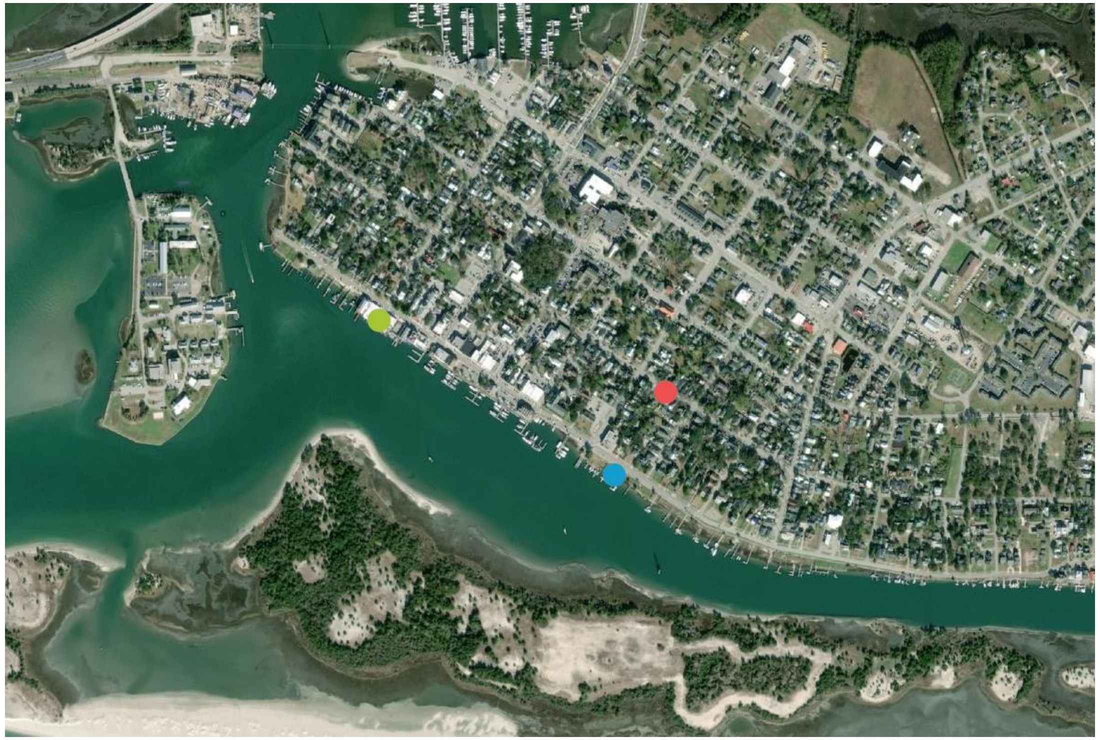


Ann Street
Marsh/Pollock
Orange Street
Inundated
Transition
Receding
Dry (<0.25 in)
Wet (>0.25 in)
N = 29
N = 61
N = 47
21%
45%
34%
31%
36%
32%
46%
54%

Results

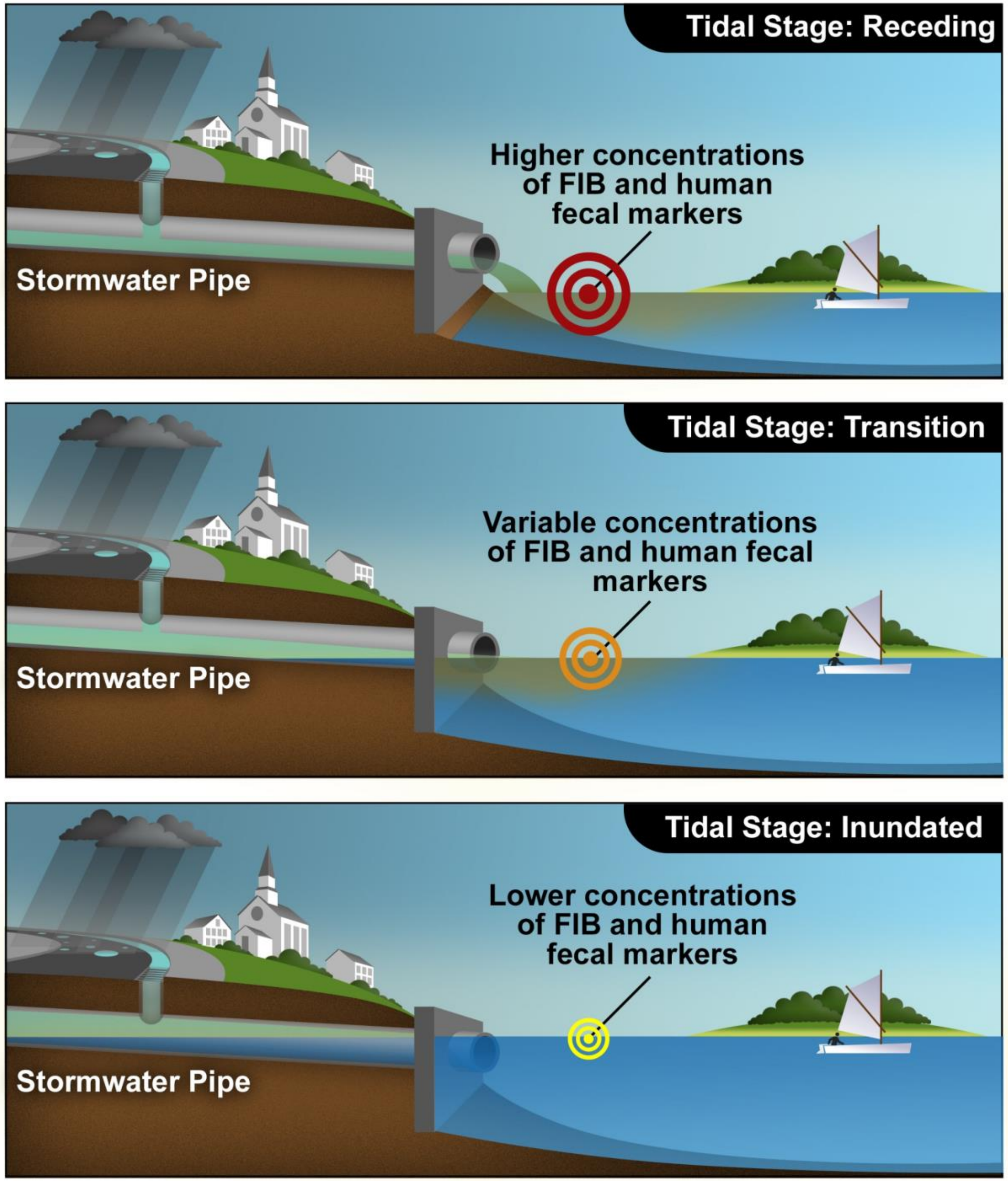


Orange Street
Marsh/Pollock
Ann Street
Log Value
6
5
4
3
2
1
0
EC (n=59)
ENT (n=59)
HF183 (n=27)
Entero1611 (n=14)
EC (n=44)
ENT (n=44)
HF183 (n=25)
Entero1611 (n=18)
EC (n=28)
ENT (n=28)
HF183 (n=11)
Entero1611 (n=12)



	FIB				qMST			
	EC		**ENT**		**ENT-qPCR**		**HF183**	
	Mean (min-max) N	Above standard	Mean (min-max) N	Above standard	Mean (min-max)	Above standard N	Mean (min-max)	Above standard N
Site	Log MPN/100 mL	EC %[a]	Log MPN/100 mL	ENT %[b]	Log copies/100 mL	ENT-qPCR%[d]	Log copies/100 mL	HF183 %[c]
OS	2.15 (0.7 – 4.05) 59	32.2	1.76 (0.7 – 4.27) 59	27.1	2.19 (0.7 – 4.5) 14	14.3	1.66 (0.7 – 3.55) 27	14.8
M/P	2.69 (0.7 – 4.78) 44	54.5	2.39 (0.7 – 4.78) 44	61.4	3.08 (0.7 – 5.03) 18	38.9	2.22 (0.7 – 4.07) 25	32.0
AS	3.62 (1.72 – 5.64) 29	75.9	3.10 (0.7 – 4.65) 29	79.3	3.96 (2.61 – 4.86) 12	83.3	2.59 (0.7 – 3.49) 11	27.3

[a] US EPA 2012 FIB recommended threshold; [b] NC DEQ ENT threshold; [c] Haugland et al., 2010; [d] US EPA 2012 molecular marker recommended threshold



Tidal Stage: Receding
Higher concentrations of FIB and human fecal markers
Stormwater Pipe
Tidal Stage: Transition
Variable concentrations of FIB and human fecal markers
Stormwater Pipe
Tidal Stage: Inundated
Lower concentrations of FIB and human fecal markers
Stormwater Pipe

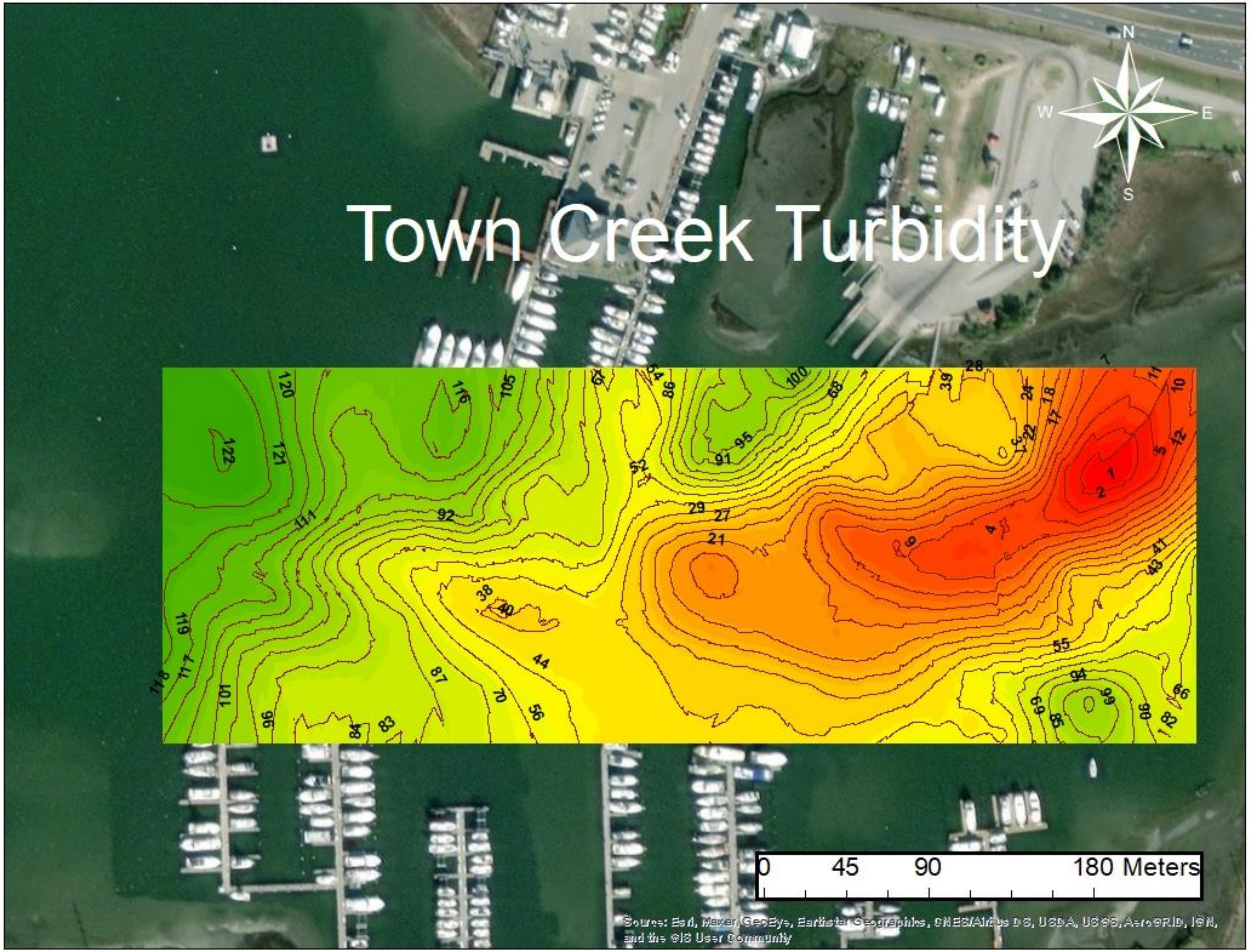
Impact of Tide Study Conclusions

- Enterococci and HF183 concentrations significantly influenced by tidal stage
  - Consider monitoring programs that incorporate tide into monitoring and municipal engineering
  - Monitoring programs based solely on rainfall are problematic
- External factors drive stormwater delivery
  - Incorporate hydrologic flow and salinity measurements more extensively
- Application of predictive modeling possible
  - Inclusion of tidal parameters necessary

Next steps:

- Autonomous boat-based monitoring of the Town Creek area of the Town of Beaufort to identify compromises in sewage infrastructure
- Post-sewage pipe construction assessment of Orange Street Outfall
- Assessment of the contribution of illicit dumping from boats in marina
- Identification of solutions for tidal inundation

Early version of Boat development by Duke Marine Robotics and Remote Sensing (MARRS) Lab


Town Creek Turbidity
N
S
W
E
0 45 90 180 Meters
Sources: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

BART-Beaufort Autonomous Remote Tracker

Acknowledgements

Funding sources

NOAA National Estuarine Research Reserve System (NERRS)

Washington Sanitation Suburban Commission (WSSC)

Dissertation Research

Dr. Matt Price

NC Coastal Reserve

Whitney Jenkins

Lori Davis

Lab members

- Denene Blackwood
- Dr. Kelsey Jesser
- Rachel Canty
- Tom Kiffney
- Tom Clerkin
- Tami Bennett
- Mark Ciesielski
- Mark Stoops

Collaborators

- Dr. Mike Piehler
- Suzanne Thompson
- Dr. Adam Gold
- Dr. Richard Smith
- Dr. Liz DeMattia, DUML Community Science Initiative
- SciREN

Town of Beaufort

- Mayor Everette Newton
- John Day
- Wade Keeler
- Donovan Willis

References

- Harwood, V. J., Levine, A. D., Scott, T. M., Chivukula, V., Lukasik, J., Farrah, S. R., & Rose, J. B. (2005). Validity of the indicator organism paradigm for pathogen reduction in reclaimed water and public health protection. *Applied and Environmental Microbiology*, *71*(6), 3163–3170.
- Herrig, I., Seis, W., Fischer, H., Regnery, J., Manz, W., Reifferscheid, G., & Böer, S. (2019). Prediction of fecal indicator organism concentrations in rivers: the shifting role of environmental factors under varying flow conditions. *Environmental Sciences Europe*, *31*(1), 1–16.
- Jofre, J., Lucena, F., Blanch, A. R., & Muniesa, M. (2016). Coliphages as model organisms in the characterization and management of water resources. In *Water (Switzerland)* (Vol. 8, Issue 5, p. 199). MDPI AG.
- Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C. H., Kossin, J., & Wu, L. (2020). Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), E303-E322.
- Love, D. C., Lovelace, G. L., Money, E. S., & Sobsey, M. D. (2010). Microbial Fecal Indicator Concentrations in Water and Their Correlation to Environmental Parameters in Nine Geographically Diverse Estuaries. *Water Quality, Exposure and Health*, *2*(2), 85–95.
- McMinn, B. R., Huff, E. M., Rhodes, E. R., & Korajkic, A. (2017). Concentration and quantification of somatic and F+ coliphages from recreational waters. *Journal of Virological Methods*, *249*, 58–65.
- NC Sea Grant. (2020). Demographic Data Offer Insights - Coastwatch. Retrieved October 19, 2020, from https://ncseagrant.ncsu.edu/coastwatch/previous-issues/2015-2/spring-2015/demographic-data-offer-insights/
- NOAA. (2020). NDBC Station Page. Retrieved October 19, 2020, from https://www.ndbc.noaa.gov/station_page.php?station=bftn7
- NOAA. (2020). Water Levels - Tides & Currents. Retrieved October 19, 2020, from https://tidesandcurrents.noaa.gov/waterlevels.html?id=8656483
- Palmer, M. A., Filoso, S., & Fanelli, R. M. (2014). From ecosystems to ecosystem services: Stream restoration as ecological engineering. *Ecological Engineering*, *65*, 62–70.
- Poulter, B., Feldman, R. L., Brinson, M. M., Horton, B. P., Orbach, M. K., Pearsall, S. H., … Whitehead, J. C. (2009). Sea-level rise research and dialogue in North Carolina: Creating windows for policy change. *Ocean and Coastal Management*, *52*(3–4), 147–153.

References

- SeaLevelRise.org. (2020). America's Sea Level Has Risen 6.5 Inches Since 1950 - Sea Level Rise. Retrieved October 19, 2020, from https://sealevelrise.org/
- Sobsey, M. D., Yates, M. V., Hsu, F. C., Lovelace, G., Battigelli, D., Margolin, A., Pillai, S. D., & Nwachuku, N. (2004). *Development and evaluation of methods to detect coliphages in large volumes of water*. Water Science and Technology.
- US EPA. (1986). Ambient Water Quality for Bacteria-1986. Washington, DC. Retrieved from https://www.regulations.gov/document?D=EPA-HQ-OW-2007-0808-0001
- US EPA. (2012). Method 1611: Enterococci in Water by TaqMan Quantitative Polymerase Chain Reaction (qPCR) Assay.
- US EPA. (2012). Recreational Water Quality Criteria. U. S. Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf
- US EPA. (2018). Method 1642: Male-specific (F+) and Somatic Coliphage in Recreational Waters and Wastewater by Ultrafiltration (UF) and Single Agar Layer (SAL) Procedure. Office of Water. Retrieved from www.epa.gov
- US EPA. (2020). Introduction to the Clean Water Act. Retrieved October 19, 2020, from https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=2788
- Wanjugi, P., Sivaganesan, M., Korajkic, A., McMinn, B., Kelty, C. A., Rhodes, E., Cyterski, M., Zepp, R., Oshima, K., Stachler, E., Kinzelman, J., Kurdas, S. R., Citriglia, M., Hsu, F. C., Acrey, B., & Shanks, O. C. (2018). Incidence of somatic and F+ coliphage in Great Lake Basin recreational waters. *Water Research*, *140*, 200–210.
- Zhang, K., & Farahbakhsh, K. (2007). Removal of native coliphages and coliform bacteria from municipal wastewater by various wastewater treatment processes: Implications to water reuse. *Water Research*, *41*(12), 2816–2824.