THE UNIVERSITY OF TENNESSEE KNOXVILLE

Patterns and drivers of nutrient trends in flood-impacted surface waters: Insights from Bayesian modeling approaches

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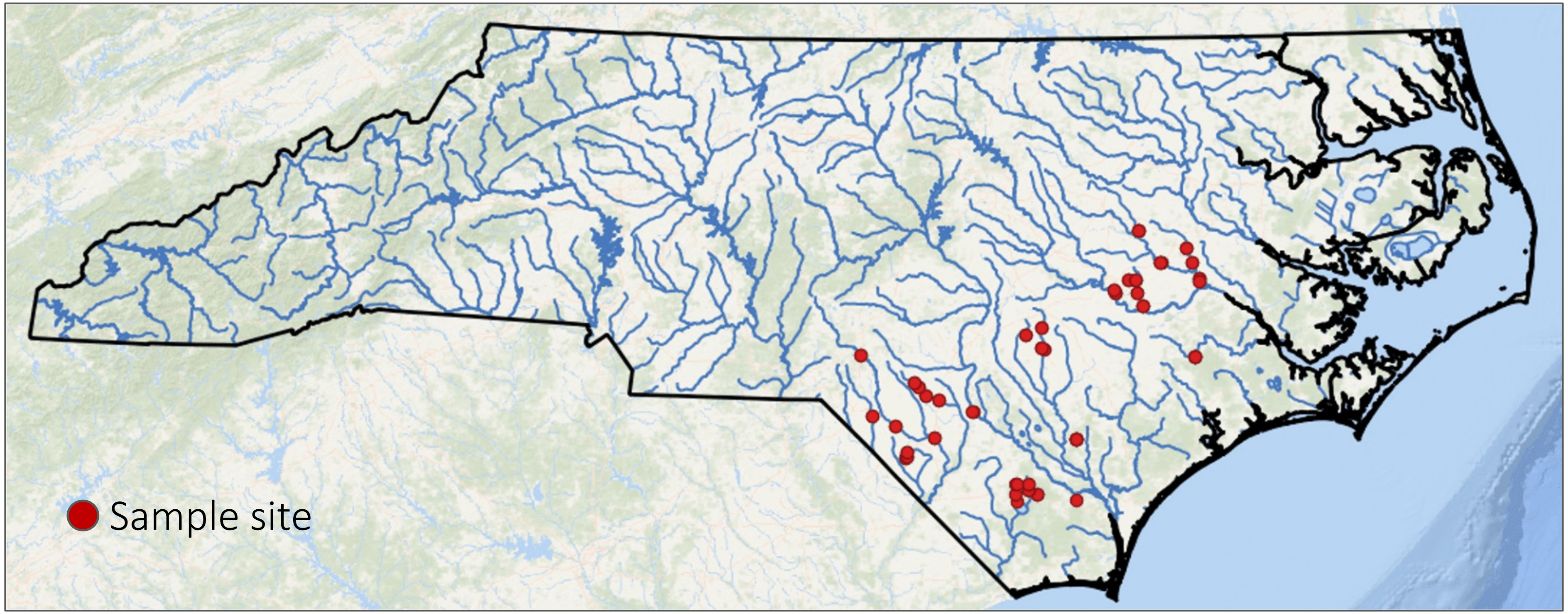
Modeling Can Inform Us of Water Quality Drivers

- Previous studies conducted descriptive flood water quality analyses
- But few studies have attempted to **explain** water quality responses in floodwaters as a function of environmental characteristics
- Study objectives:
  - Quantify the flood water nutrient concentrations in the North Carolina Coastal Plain after Hurricane Florence
  - Construct a statistical model that explains flood nutrient responses as a function of landscape characteristics
  - Assess the variables that best explain the magnitude of the nutrient response

Credit: https://giphy.com/explore/caught-in-a-flood



Hurricane Florence landfall:
September 14, 2018

Phase 1: September 21 – 28, 2018

Phase 2: October 18 – 19, 2018

… a year later…

Phase 3: September 28, 2019

Phase 4: October 18, 2019

Nutrients analyzed:

- TKN
- NH_3/NH_4^+ (TAN)
- NO_3^-/NO_2^-
- TP
- OPO_4^{3-}

Explanatory Variables:

variables that we believe would influence flood water quality

- Hydroclimatic factors:
  - mechanisms of flooding and transport
    - Antecedent rainfall
    - Watershed area
    - Flooded area
- Pollution non-point and point sources:
  - potential pollutants
    - CAFOs
    - WWTPs
    - Population density
- Land-use characteristics:
  - mechanisms of flooding and transport and potential pollutants
    - Drainage class
    - Land cover

Key Findings

- CAFO variables were consistently important in explaining nutrient and pathogen concentrations during flooding, but also during non-flood conditions
- WWTPs were likely sources of inorganic N exports associated with Hurricane Florence
- Developed flooded area was important in Phase 1, when flooding was the most extensive

Image taken during Phase 1 floodwater sampling

Thank You!
Questions?

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Patterns and Drivers of Nutrient Trends in Flood-Impacted Surface Waters

Dr. Emine Fidan, Assistant Professor, Biosystems Engineering

Image: https://www.diskusari.com.hr/the-xinguary-project-by-andras-kis-and-nandi-hivata

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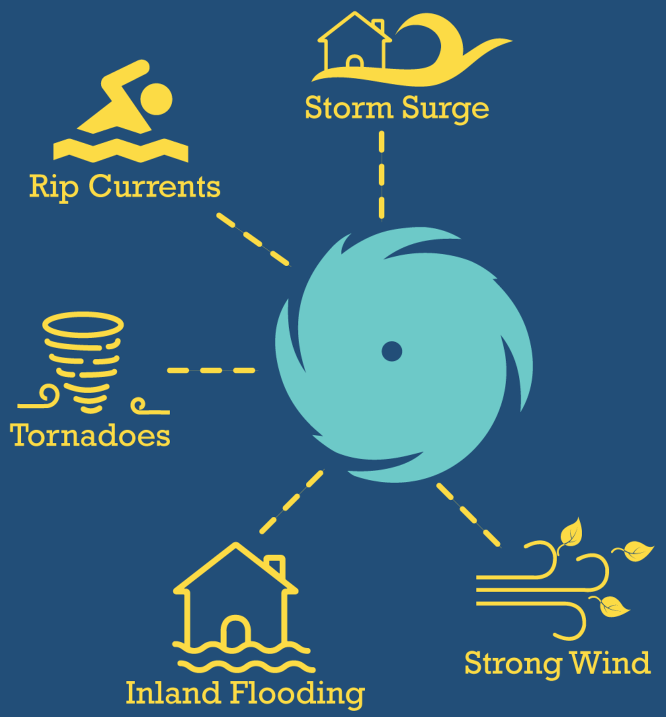
Hurricanes are extreme events that create devastating impacts on the public, but also the environment.



High speed winds, intense rainfall, flooding, and physical devastation from these extreme storm events have the capacity to **influence water quality, biodiversity, and even human health**.

Compared to our understanding of rainstorms and stormwater, the impacts of major storm events, like hurricanes, are understudied.

Credit: NOAA National Weather Service

Data Analytics:

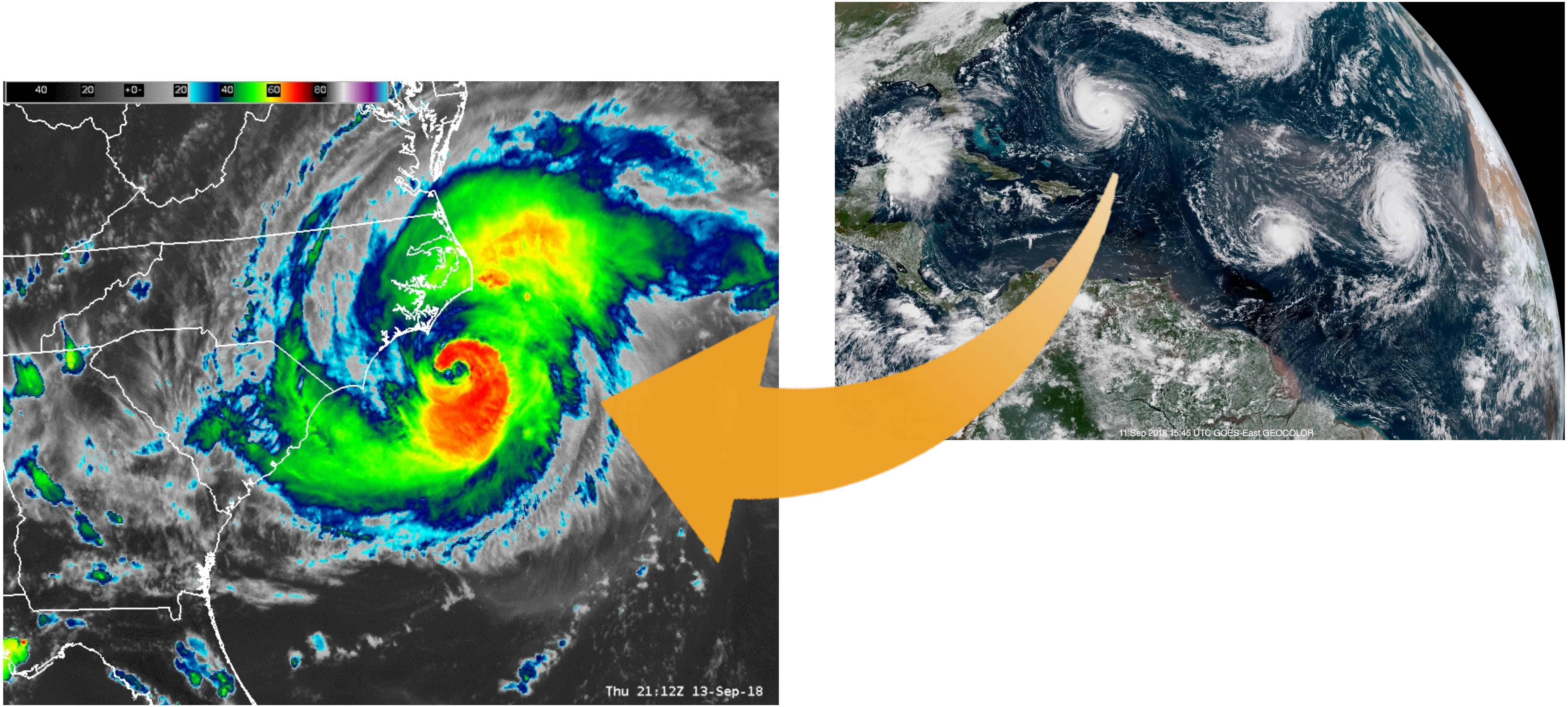
The science of analyzing data and converting it to knowledge

- Hydrology and hydraulics are **complex** during hurricane events and flood conditions
- Environmental data is **limited** during extreme storm events

Empirical modeling and data analytics methods have the capabilities to convert our limited data into knowledge and provide insights on surface water dynamics.

Credit: Hevo Data

Hurricane Florence (2018)




Credit: North Carolina Highway Patrol

Concentrated Animal Feeding Operation (CAFO)

Credit: centerforfoodsafety

Wastewater Treatment Plant (WWTP)

Credit: AP Photo/Gerald Herbert

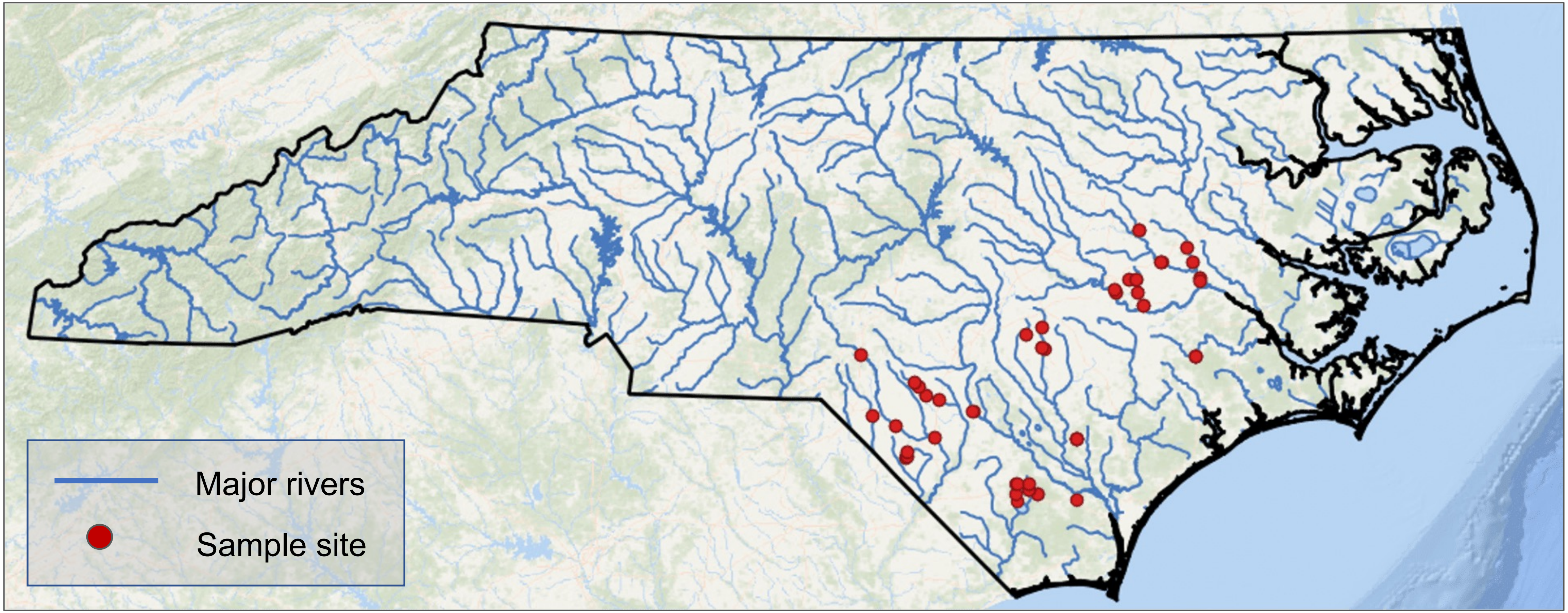
Modeling Can Inform Us of Water Quality Drivers

- Previous studies conducted descriptive flood water quality analyses
- But few studies have attempted to **explain** water quality responses in floodwaters as a function of environmental characteristics
- The development of empirical flood water quality models could
  - quantify water quality hazards
  - inform public health responses

Credit: https://giphy.com/explore/caught-in-a-flood

Study Area

- North Carolina Coastal Plain



Flood Sample Collection

Hurricane Florence landfall:
September 14, 2018

Phase 1: September 21 – 28, 2018
Phase 2: October 18 – 19, 2018

... a year later...

Phase 3: September 28, 2019
Phase 4: October 18, 2019

Water Quality Constituents

- fecal coliform (*E. coli*)
- swine microbial source target (Pig2Bac)
- human microbial source target (HF183)
- nutrients (TKN, TP, TAN, NO_3^-/NO_2^-, OPO_4^{3-})
- pathogens (Salmonella, Arcobacter, Listeria)

Image taken during Phase 3 sampling

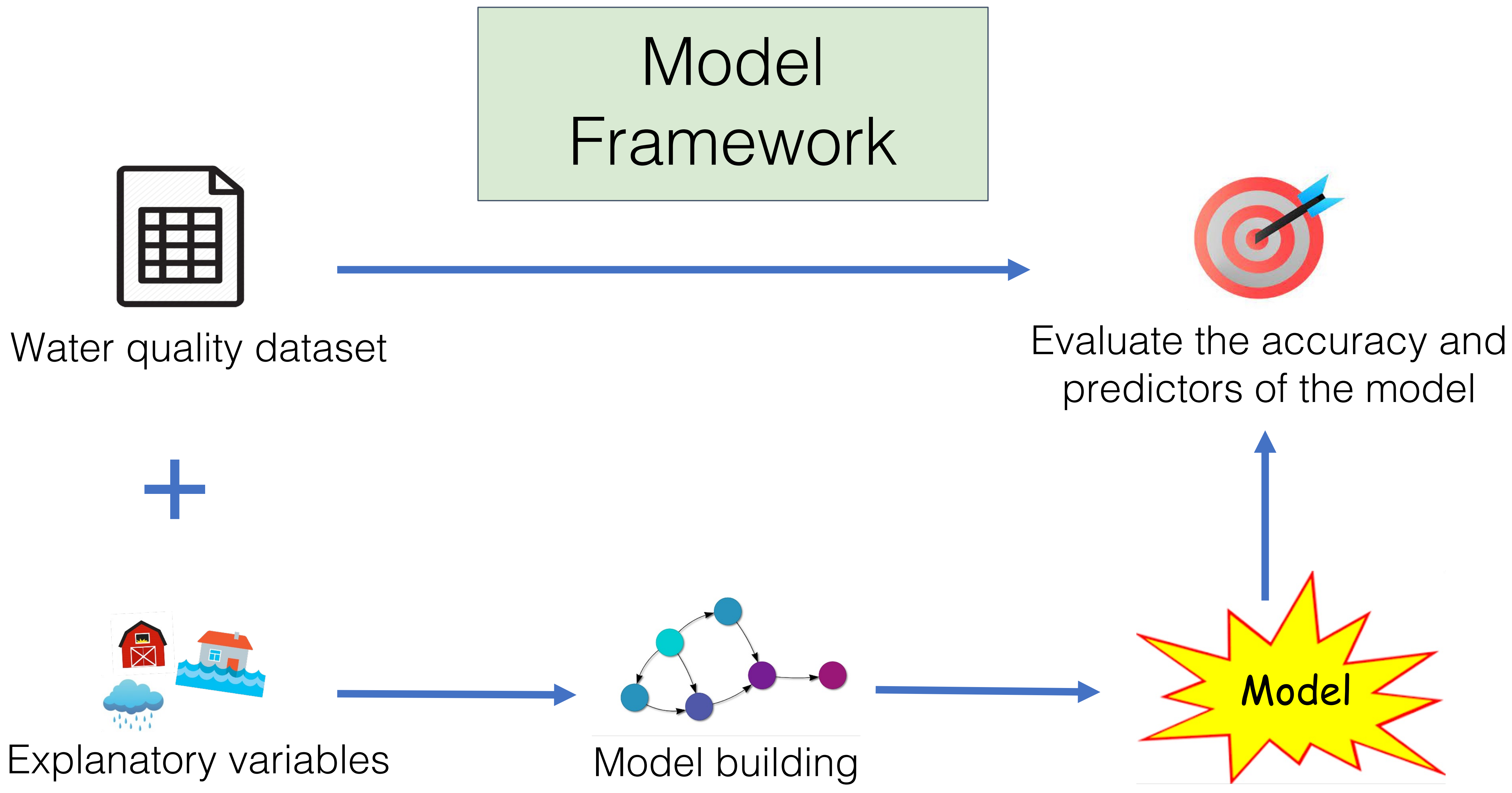
Explanatory Variables:
variables that we believe would influence flood water quality

- Hydroclimatic factors:
  mechanisms of flooding and transport
- Pollution non-point and point sources:
  potential pollutants
- Land-use characteristics:
  mechanisms of flooding and transport
  potential pollutants

Explanatory Variables:

variables that we believe would influence flood water quality

- Antecedent rainfall
- Watershed area
- Flooded area
- Distance to nearest upstream CAFO
- Number of CAFOs
- Total population
- Distance to nearest upstream WWTP
- Drainage class
- Land cover


Model
Framework
Water quality dataset
Evaluate the accuracy and
predictors of the model
+
Explanatory variables
Model building
Model

Multivariate Spatial Bayesian Model

- A statistical model was selected due to small sample size.
- This new model used relationships between the different water quality responses to help increase model accuracy.

$$Y_k(s_i,t) = \beta_{0,k} + \sum_{j=1}^{p} \beta_{j,k} X_j(s_i,t) + \omega_k(s_i,t) + \varepsilon_k(s_i,t)$$

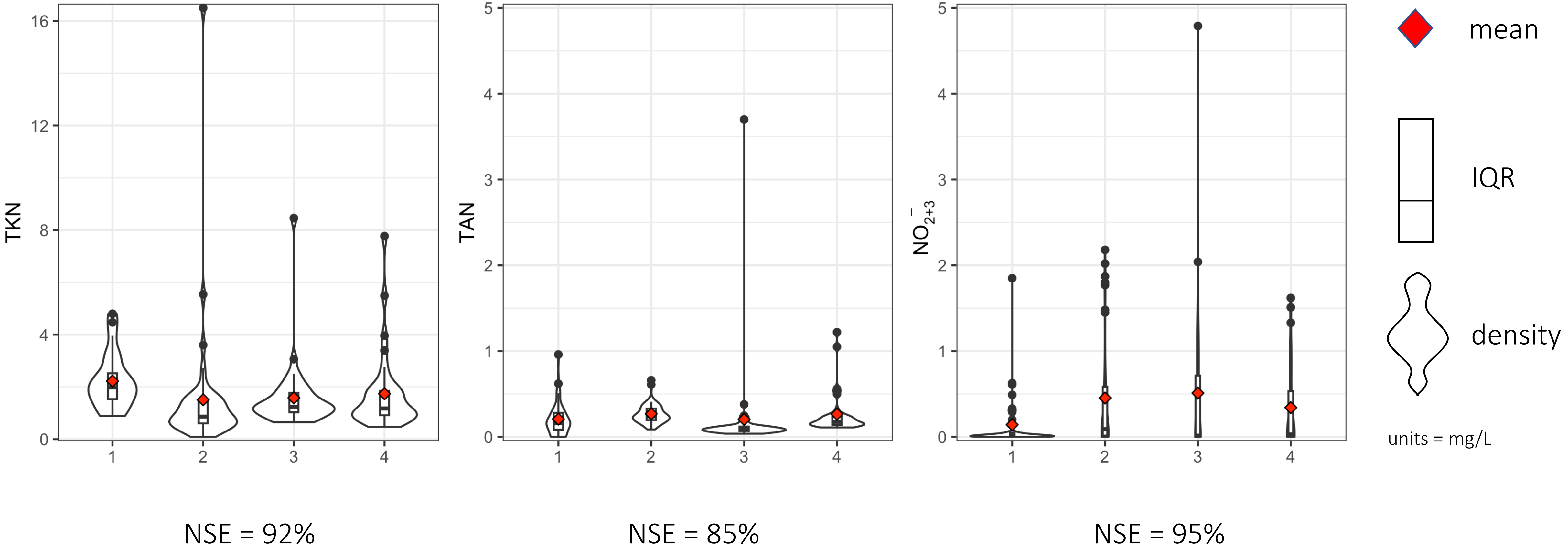
water quality response

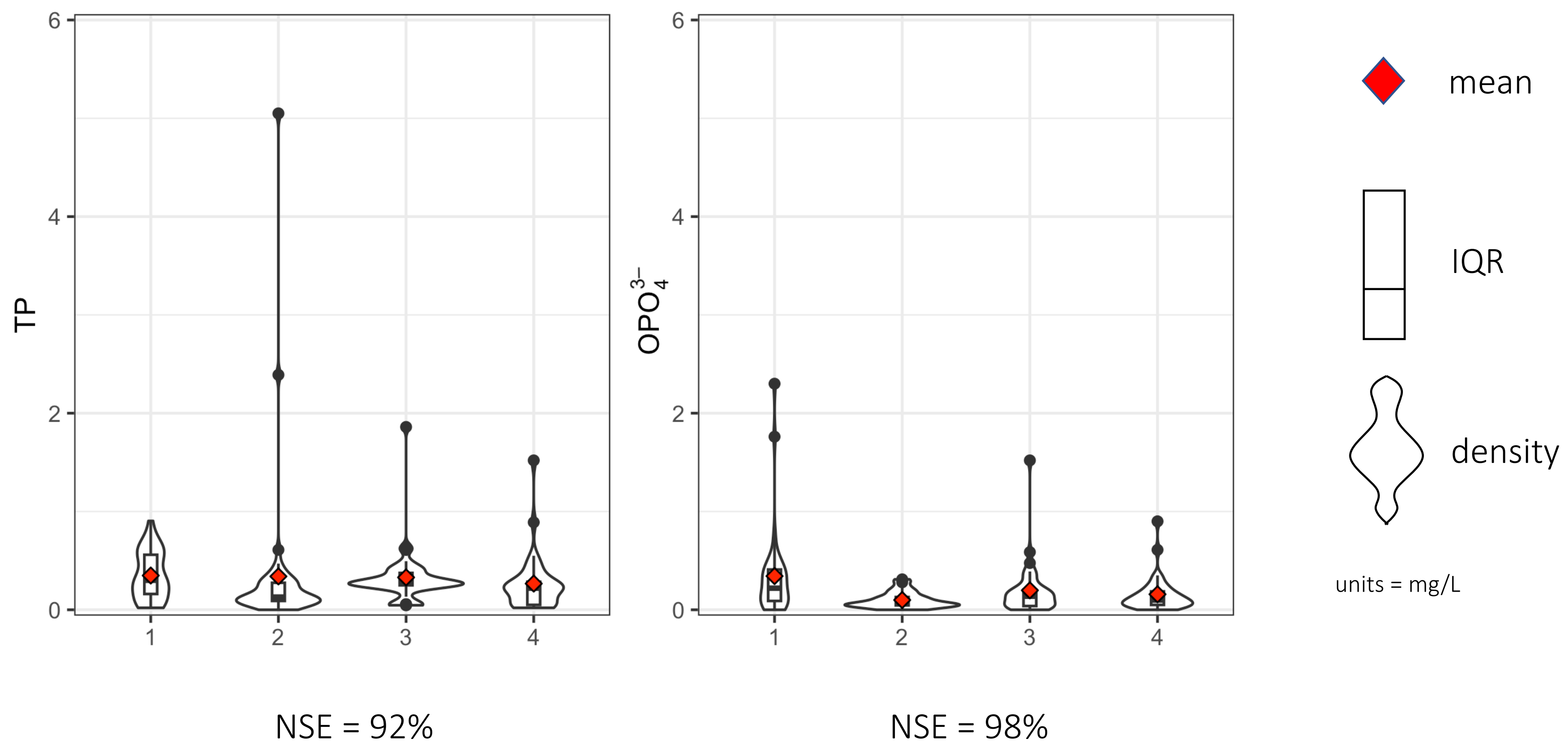
mean trend

correlated residuals

independent residuals

Y is the concentration for nutrient **k** at location $\mathbf{s_i}$ and time **t**, **p** is the number of covariates,
X are the covariate values, **β** are the covariate coefficients,
ω is the term that captures correlation across space and responses


TKN
16
12
8
4
0
1
2
3
4
NSE = 92%
TAN
5
4
3
2
1
0
NSE = 85%
NO_{2+3}^{-}
NSE = 95%
mean
IQR
density
units = mg/L


6
4
2
0
TP
1
2
3
4
NSE = 92%
6
4
2
0
OPO_4^{3-}
1
2
3
4
NSE = 98%
mean
IQR
density
units = mg/L

	Phase 1	Phase 2
TKN	2-Day Rainfall 5-Day Rainfall CAFO	2-Day Rainfall Day-of Rainfall 7-Day Rainfall
TAN	3-Day Rainfall WWTP CAFO	CAFO 5-Day Rainfall
NO_{2+3}^{-}	3-Day Rainfall Developed Flooded Area WWTP	3-Day Rainfall CAFO 5-Day Rainfall
TP	3-Day Rainfall CAFO Developed Flooded Area	2-Day Rainfall Day-of Rainfall CAFO
OPO_4	Cropland:Wetland Area CAFO Day-of Rainfall	2-Day Rainfall Day-of Rainfall 7-Day Rainfall

- Rainfall was the most important driving factor for nutrient concentrations
- CAFO variables were important during flood and non-flood conditions
- WWTP variables were important for ammonium/ammonia and nitrate/nitrites during Phase 1
- Land use variables were important during Phase 1

Findings

- CAFO variables were consistently important in explaining nutrient and pathogen concentrations during flooding, but also during non-flood conditions
- WWTPs were likely sources of inorganic N exports associated with Hurricane Florence
- Developed flooded area was important in Phase 1, when flooding was the most extensive

Image taken during Phase 1 floodwater sampling

Fidan Ecological Systems Engineering Lab

- Water quality
- Water resources management
- Ag and Ecological health
- Data-based modeling
- GIS
- Remotely sensed imagery
- Big data management
- Decision-making tools