Hurricane flooding and water quality issues: opportunities for increased resilience

Danica Schaffer-Smith[1], Soe Myint[2], Rebecca Muenich[3], Daoqin Tong[2], and Julie DeMeester[4]

[1]Center for Biodiversity Outcomes, Arizona State University & The Nature Conservancy
[2]School of Geographical Sciences & Urban Planning, Arizona State University
[3]School of Sustainable Engineering and the Built Environment, Ira A. Fulton Schools of Engineering, Arizona State University
[4]The Nature Conservancy

November 22, 2022

Abstract

Hurricanes that cause damage to lives and property are often accompanied by poor water quality that threatens the health of human communities and aquatic species. North Carolina has experienced 3 devastating 500-yr storms within 2 years; wastewater treatment plants and sanitary sewer overows occurred up to 300 km inland, as well as coal ash spills, breaches of confined animal feeding operation (CAFO) waste lagoons, and numerous fish kills. Many in-situ sensors went offline and hazardous conditions precluded field sampling during and after these events. Publicly available satellite data enables delineation of flooding over broad areas, which can aid in quantifying the extent of flood exposure and potential water quality impacts. We mapped flooding across the North Carolina Piedmont and Coastal Plain due to Hurricane Matthew (2016) and Hurricane Florence (2018) with Sentinel-1 synthetic aperture radar. We assessed how impacts were distributed across indicators of social vulnerability at the census tract level and freshwater ecological vulnerability at a watershed scale using quantile regression. Finally, we identied flood-prone infrastructure relevant to water supply and treatment, and mapped locations where nature-based solutions could be implemented to store floodwaters and process contaminants. Flooding mapped with >91% accuracy extended beyond the 500-year floodplain—furthermore, the legal floodplain systematically underestimated impacts to more vulnerable human populations and surface waters. Repeated flooding affected both point and non-point sources of nutrients, including 188 wastewater treatment plants representing >46% of treatment capacity and 77 swine CAFOs that generate ˜ 478,926,961 tons of manure per year. Conservation of ˜4,600 ha of currently unprotected forest and wetland, and restoration or changes in land management on ˜3,100 ha represent key opportunities to protect human and natural communities under future storms. Our results suggest that current flood hazard maps are inadequate for resilience planning. Changes to design standards, land-use planning policies, and operation of infrastructure that conveys and treats water are warranted to improve floodplain resilience.

Poster #H53L-1942

Hurricane flooding and water quality issues: opportunities for increased resilience

Danica Schaffer-Smith[1,2], Soe W. Myint[3], Rebecca L. Muenich[4], Daoqin Tong[3], Julie E. DeMeester[2]

[1] Center for Biodiversity Outcomes, Julie Ann Wrigley Global Institute of Sustainability, Arizona State University, Tempe, AZ. [2] The Nature Conservancy North Carolina, Durham, NC.

[3]School of Geographical Sciences & Urban Planning, ASU. [4]School of Sustainable Engineering & the Built Environment, ASU. Contact: d.schaffer-smith@tnc.org

Motivation and objectives

Hurricanes are often accompanied by poor water quality threatening humans and aquatic species[1-5] (e.g., Fig. 1), yet impacts are difficult to measure[6]. Increased storm frequency and intensity, coupled with ongoing land use change, will exacerbate impacts to vulnerable communities and ecological systems[6-8]. North Carolina experienced two '500-yr' storms 2016-2018, presenting a timely case for assessing floodplain resilience to inform interventions. Flood extent mapping can help to quantify potential impacts[9].

Figure 1. Hurricane-related water quality issues include low oxygen and fish kills (A: Lock & Dam 1, Cape Fear River) and widespread distribution of harmful contaminants (B: swine facility near Kinston, NC).

Objectives:

1) **Delineate flooding from Hurricanes Matthew (2016) and Florence (2018).**
2) **Assess implications of differences between exposure compared to hazard maps vulnerable human communities and freshwater networks.**
3) **Identify opportunities to reduce future flooding and water quality problems.**

Methods

- We mapped flood extent with Sentinel-1 radar[10], topography[11-13], landcover[14,15], and floodplain[16] data using random forest models[17] in Google Earth Engine[18]. We used high-resolution aerial photography[19] and high water marks[20,21] for model validation.
- To examine potential impacts on vulnerable human populations[22] and freshwater networks[23] across flood hazard and exposure areas, we used quantile regression[24].
- We identified flood-prone pollutant sources[25,26] and water supply and treatment infrastructure; in addition we mapped locations where nature-based solutions could reduce flooding and improve water quality.

References

1. Khan, S.J., et al. (2015) *Water Res.*, 85.
2. Cann, K.F., et al. (2013) *Epidemiol. Infect.*, 141.
3. Schwarzenbach, R.P. (2006) *Science*, 313.
4. DeLorenzo, M.E., et al. (2001) *Environ. Toxicol. Chem.*, 20.
5. Wing, S., et al. (2002) *Environ. Health Perspect.*, 110.
6. Tapsell, S.M., et al. (2002) *Philos. Trans. R. Soc. Lond. Ser. Math. Phys. Eng. Sci.*, 360.
7. Brouwer, R., et al. (2007) *Risk Anal.*27.
8. Kotzee, I., et al. (2016) *Ecol. Indic.*, 60.
9. Boryan, C.G., et al. (2018). *IGARSS 2018*.
10. Copernicus (2018) Sentinel-1 SAR data.
11. Nobre, A.D., et al. (2011) *J. Hydrol.*, 404(1-2).
12. USGS (2015) 10m National Elevation Dataset.
13. Terziotto, S. & Hopkins, K.G. (2018) Geomorphological features of North Carolina.
14. Homer, C.G., et al. (2015) *Photogramm. Eng. Remote Sensing*, 81(5).
15. Pekel, J-F., et al. (2016) *Nature*, 540(7633).
16. Wing, O., et al. (2017) *Water Resour. Res.*, 53(9).
17. Breiman, L. (2001). *Machine Learning*, 45(1).
18. Gorelick, N. et al. (2017) *Remote Sens. Environ.*, 202.
19. NOAA & FEMA (2018) Emergency Response Imagery.
20. USGS (2018) High water marks.
21. NC Division of Emergency Management (2018) High water marks.
22. Flanagan, B.E., et al. (2011) *J. Homel. Secur. Emerg. Manag.*, 8.
23. Benner, R., et al. (2014) North Carolina's Freshwater Resilience, The Nature Conservancy.
24. Koenker, R. (2005). *Quantile Regression*. Cambridge: Cambridge University Press.
25. NC Department of Environmental Quality (2018) Online GIS.
26. The Environmental Working Group & Waterkeeper Alliance (2016) North Carolina poultry facility locations.
27. Arnold, J.G., et al. (2012) *Trans. ASABE*, 55.

Hazard mapping underestimated impacts on vulnerable systems

Across the Piedmont and Coastal Plain of North Carolina, we identified hurricane flooding (>91% accuracy) beyond hazard zones—Hurricane Florence exceeded the 1% annual probability zone by ~23% (Fig. 2). Furthermore, the legal floodplain underestimated impacts for communities with higher proportions of older adults, disabilities, unemployment, and mobile homes, as well as for headwater streams with restricted elevation gradients.

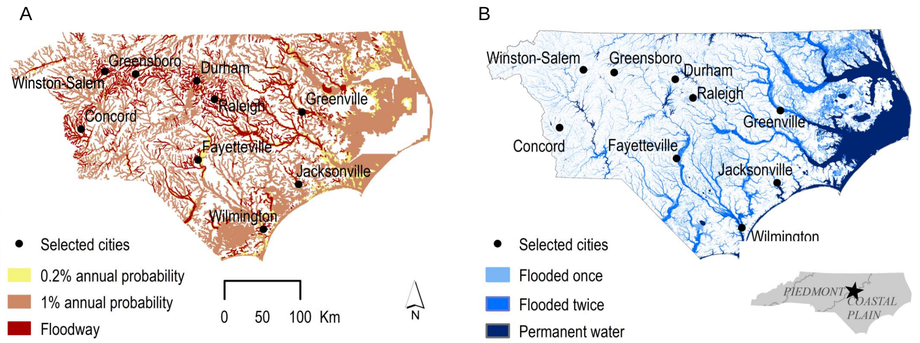
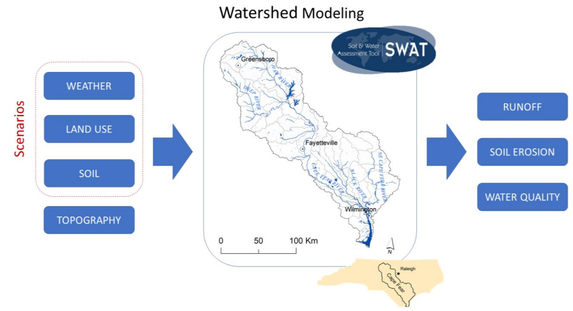


Figure 2. Areas well beyond state mapped flood hazard zones (A: 0.2% probability = '500-yr' floodplain, 1% annual probability = '100-yr floodplain) were affected by flooding from Hurricanes Matthew and Florence, as detected with Sentinel-1 SAR (B).

Implications and Next Steps

- **Results suggest that current hazard mapping is inadequate for resilience planning to protect vulnerable systems.**
- **Modification of design standards, land-use policies, and operation of infrastructure that conveys and treats water and pollutants are warranted.**
- **Interventions will be more thoroughly assessed using a Soil and Water Assessment Tool Model[27] in collaboration with the U.S. Geological Survey.**



Potential impacts and opportunities

Repeated flooding affected numerous potential sources of water contaminants, including 218 wastewater treatment plants (~55% capacity), and 91 swine farms (~500 million tons/yr manure). To illustrate potential impacts due to flooding beyond the 100-yr floodplain (1% annual probability), we use the example of nutrient sources subject to distinct regulatory limitations, including wastewater treatment plants (National Pollution Discharge Elimination System [NPDES] permitted point-source), swine facilities (NPDES permitted point-source, or non-point source) and poultry facilities (non-point source) (Fig. 3). We also identified ~4.8 million km^2 of forests and wetlands lacking formal protection, and ~1.7 million km^2 of working lands where restoration or management changes could be considered.

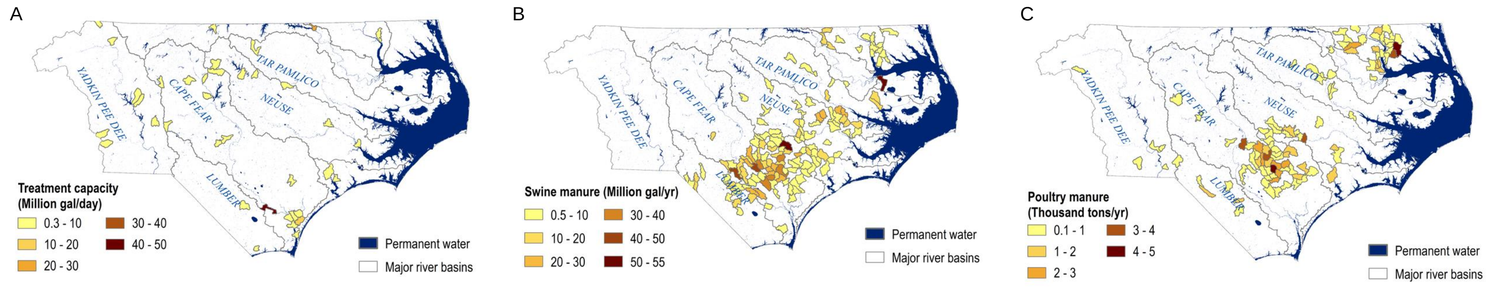


Figure 3. Potential nutrient load by watershed from facilities beyond the '100-yr' floodplain affected by Hurricanes Florence and Matthew. A: Permitted wastewater treatment plants. B: Permitted swine farms, which also include lands where waste is regularly applied. C: Poultry farms not regulated by NPDES.

Copernicus Sentinel-1 SAR data were processed by ESA. Applied Flow Technology provided modeled 1,000-year floodplain data. The Environmental Working Group provided poultry facility location data. Funding was provided by a NatureNet Science Fellowship.

Photo: NASA Landsat 8 image of the Trent River, North Carolina, September 19, 2018.