Impact of Hurricane Florence on well quality in communities surrounding coal ash impoundments in North Carolina

1. PROBLEM STATEMENT AND OBJECTIVES

Hurricane Florence made landfall on the North Carolina (NC) coast on September 14 as a Category 1 hurricane. Over past three days, Florence has produced record-setting rainfall, with areas along the coast receiving 20+ inches.[1] River flooding forecasts suggest that Cape Fear, Lumber, and Neuse Rivers will crest well above their flood stage.[2] As NC residents return home, those reliant on unregulated private wells will be solely responsible for ensuring the safety of their drinking water supply.[3] Our prior RAPID flood-related research on well water quality after the August 2016 Louisiana floods and Hurricanes Harvey and Irma led to several key findings including:[4,5] 1) private wells are at an increased risk of fecal contamination;[6] 2) there are potential risks associated with well water pathogens that go undetected when monitoring only for indicator bacteria;[6,7] 3) specific flooding characteristics (e.g., wellhead submersion) are associated with increased *Escherichia coli* positivity rates;[6] 4) educational platforms are needed to train well users on importance of water testing and appropriate treatment methods;[6,8] and 5) prevailing well water disinfection protocols lack efficacy research.[9,10] In general, most well users in our flood-impacted communities only sampled for indicator bacteria, but given the well-known health impacts exposure to heavy metals, inorganic contaminants must also be evaluated.

There are numerous industrial sites along the NC coast, ranging from hog farming to hazardous waste storage to coal ash impoundments.[11] Flooding has already resulted in a dam failure at the Sutton Power Plant in Wilmington, which discharged an estimated 1,530 cubic meters (approximlatey18 dump trucks full) of coal ash material into a recreationally-used lake and associated floodwaters.[12] A second breach at this site was reported only a few days later.[13] Two other coal ash impoundments – H.F. Lee Plant in Goldsboro along the Neuse River and W.H. Weatherspoon Plant in Lumberton along the Lumber River – are in danger of failing as these sites have been inundated due to the flooding of adjacent rivers.[14] Moreover, the NC Department of Environmental and Natural Resources rated most of the state's 37 coal ash impoundments as high hazards for potential dam failures during flooding back in 2012.[15] While the exact composition of coal ash can vary between power plants, previous studies have observed the presence of potentially harmful contaminants such as arsenic, boron, chromium, lead, mercury, molybdenum, strontium, and vanadium.[16–20] While microbial contamination attributed to widespread flooding from Hurricane Florence is largely expected based on prior recovery research,[6,7,21,22] presence of industry byproducts are almost completely unexplored. With an 85,000+ well users residing in these three counties where coal ash impoundments have been impacted,[23] there is a critical need to evaluate heavy metal contamination.

The primary source of support for NC well owners is their local county health department, but our prior work has shown that well programs across NC are fragmented and lack sufficient resources to ensure well water quality.[24] During a disaster, it can be even more challenging for government agencies to assist the well community due to limited knowledge of well locations and low participation in testing.[25–27] Through this RAPID grant, our team will conduct temporal and spatial sampling to better understand flood-associated well water hazards in communities surrounding coal ash impoundments and explore these communities' well recovery behaviors. Specifically, this research aims to: *1) characterize well water heavy metal and bacterial contamination in counties with flood-impacted coal ash impoundments; 2) examine well users' risk perceptions, behaviors, and resource needs related to flood preparation and recovery; and 3) determine site-specific hazard proximities, hydrogeologic factors, well construction characteristics, and well user behaviors that increase the likelihood of contamination.*

2. INTELLECTUAL MERIT

Microbial contamination is often the only well water contaminant to be tested by well owners. Thus, there are little data documenting the natural or manmade sources of other well contaminants, especially in areas near coal ash impoundments. There is also limited research regarding the knowledge gaps and recovery needs for well users impacted by floods and industrial byproducts such as coal ash. These knowledge gaps are especially relevant after Hurricane Florence because a) coal ash impoundments and spills have previously contaminated drinking water supplies; b) well stewardship knowledge and behaviors are often insufficient to ensure well water quality; and c) prevailing indicator bacteria tests cannot guarantee well water safety.

a) **Coal ash impoundments and spills have previously impacted drinking water,** as they have released toxic heavy metal into the environment. The 2014 Dan River coal ash spill released 39,000 tons of coal ash from a broken drainage pipe, and nearby waters and soils were contaminated with elevated levels of arsenic and selenium.[28] The Kingston Fossil Plant coal ash spill released a billion gallons of coal ash slurry into surface water bodies, which contaminated nearby rivers and sediments with high levels of arsenic, strontium, and boron.[29] Aside from sudden release events or spills, studies have also examined passive leaching of coal ash related metals such as antimony, arsenic, boron, cadmium, selenium, and strontium into nearby surface water sources.[17,30,31] Naturally occurring hexavalent chromium has also been detected in NC private wells, and researchers attribute its presence to the natural geologic sources.[32] In 2016 Hurricane Matthew highlighted vulnerability with coal ash impoundments, as there was a dam breach at Lee Stream Plant in Goldsboro.[33] Flooding of coal ash impoundments present risks to private well users, as floodwaters can directly contaminate wells through poor wellhead seals or via contaminant of local groundwater supplies. To date, no studies have examined well water contamination from flood-impacted coal ash impoundments. However, environmental tracer methods developed for non-flooding conditions can be used to evaluate the potential contribution of coal ash impoundments to inorganic contaminants observed in flooded wells. Specifically, studies have identified distinctive boron and strontium isotope ratios in coal ash effluent samples and suggested their potential use as environmental tracers of coal contamination.[34,35] Thus, it is imperative to evaluate well water quality surrounding impacted coal ash impoundments, but it is also important to critically identify contaminant sources, so that emergency planning can be targeted to high risk sites and exposure routes.

b) **Well stewardship knowledge and behaviors are often insufficient to ensure well water quality,** based on our surveys of flood-impacted well owners in Louisiana and Texas.[6,8] Well owners expressed dissatisfaction with both preparation and recovery resources provided by federal and state officials. In addition, the most widely applied treatment approach after floods – shock chlorination for well water disinfection – was found to be inconsistently effective, with similar rates of bacterial contamination in wells that were and were not disinfected. Often well owners lacked knowledge about well construction characteristics like well depth, and such information is critical for estimating appropriate chlorine dosage.[9,26] The biggest information need among survey respondents was for location-specific well water testing recommendations and treatment approaches that are specific to contaminants most commonly identified in their aquifers.[8] Local and state officials often do not have readily available resources with recommendations for well water contaminant testing or testing locations. Moreover, some resources that are being distributed were found to be outdated and included testing facilities that did not provide services to private well owners.[8,9] Communication and education of well owners is also complicated by the fact that no comprehensive databases existed on wells, well owners, or well hazard source locations.[25] This is further complicated by well owner migration and movement during flooding events.

Continued evaluation of site-specific resources and educational needs is essential, especially in socially isolated communities.

c) **Absence of indicator bacteria cannot guarantee the safety of drinking water supply** because coliform bacteria are not associated with all flood-related hazards. As researchers have highlighted increased contamination post flooding,[6,7,21,22] well recovery strategies suggest that flood-impacted wells are at high risk for microbial contamination and recommend coliform bacteria testing.[36] The recovery guidelines state that if the well water tests negative for coliform bacteria, then the water is safe for consumption, which is problematic as it does not address inorganic contaminants. [9,36] Researchers have shown that abundance, diversity and activity of microorganisms vary considerably based on coal ash impoundment characteristics and water characteristics.[37,38] After Hurricane Harvey, our team uncovered high rates of microbial contamination along with inorganic contaminant concerns.[6] For example, low-level arsenic concentrations (1-9 ppb) were observed in 76% of wells tested, with 13% of wells above 5 ppb. We speculate this arsenic was naturally occurring and not associated with the flooding event. However, sole reliance on coliform tests would not have been appropriate or adequate and could have potentially provided residents a false sense of security. Sampling campaigns must provide a more comprehensive analysis of flood-related hazards. Sole reliance on indicator bacteria tests may place communities surrounding industry activities and/or waste facilities at risk of exposure due to inappropriate of testing strategies.

The proposed RAPID effort will provide a holistic water quality assessment of private wells surrounding flood-impacted coal ash impoundments. Our results will continue to help provide site-specific insights into the recovery and resource needs of well water reliant communities which reside in difficult to reach and socially isolated areas. These communities are also often subject to disproportionate social and environmental burdens, which may influence their well recovery behaviors. Emergency well recovery strategies, including testing and treatment, must consider the unique characteristics of a community, before outreach approaches can be tailored to address their greatest contamination threats.

3. APPROACH

Three RAPID grant objectives will be achieved through a combination of citizen science sampling campaigns and statistical modeling.

Objective 1: Characterize well water heavy metal and bacterial contamination in counties with flood-impacted coal ash impoundments. Virginia Tech and UNC-IE will collaborate with local community leaders and partners to conduct a citizen science sampling effort in two of the three counites with flood-impacted coal ash impoundments – H.F. Lee Plant in Goldsboro, L.V. Sutton Plant in Wilmington, and Weatherspoon Plant in Lumberton. We will determine which sites based on the impact of flooding on the coal ash impoundments and percentage of well users in surrounding flooded area. We will distribute 100 free well water sampling kits in each county for county-wide testing, which will be advertised through local media outlets, community partners, and recovery officials. In addition, we will provide another 15 free sampling kits to homes immediately surrounding the coal ash impoundments, which will be distributed through a door-to-door campaign. These wells will be identified and targeted with the assistance of community leaders and partners. Participants will receive a sample kit that contains three sterile bottles, a consent form, sampling instructions, and our hurricane well survey. All samples will be collected from a working tap after a 5-minute flush. Upon return of the sampling kit, residents will be offered a free ZeroWater pitcher, as our team has confirmed that these filters are effective in removing heavy metals. Water analysis will be performed at Virginia Tech within 18 hours of collection. Participants will be notified within 2-3 days of coliform bacteria results by email or phone and within 1 week of inorganic results by email or mail. Contact information for the Virginia Tech and UNC-IE team will be provided, along with contact information for recovery resources, and local government health departments. After results dissemination, we will organize community meetings to discuss interpretation of water testing reports, community-wide results, and address any well water related questions.

All water samples will be analyzed for total coliforms, *E. coli*, nitrates, phosphates, metals, pH, and conductivity. A subset of total coliform positive and negative samples will receive a comprehensive analysis of pathogens and opportunistic pathogens, including *Legionella spp., L. pneumophila, Mycobacterium spp., M. avium,* and *Naegleria fowleri*. These results will be used in our multi-state pathogen characterization for flood-impacted microbial health risks of private wells.[5] Participants will be contacted after 3 months to retest their well water to evaluate changes in drinking water quality over time. This comprehensive sampling approach will be the first to holistically assess well water quality after a flooding disaster. Comprehensive sampling is pivotal in determining appropriate remediation strategies, as microbial remediation efforts such as shock chlorination will not remove inorganic parameters. Thus, communities impacted by industry byproducts, such as coal ash, must be advised to treat for both types of contaminants. Information gained from this emergency sampling campaign will provide insights into types of well water flooding hazards and assess the need to provide comprehensive testing after future flooding events.

Objective 2. Examine well users' risk perceptions, behaviors, and resource needs related to flood preparation and recovery. Our hurricane well survey will be modified and updated based on results from its deployment after Hurricanes Harvey and Irma. This survey will provide information about: 1) resident demographics; 2) extent of flooding and well damage, 3) wellhead protections; 4) well water use and consumption patterns; 5) recovery treatment strategies; 6) prior flood and natural disaster experiences; 7) history of well water reliance; 8) government, social, and NGO support; 9) government trust; and 10) relative risk perceptions. During our follow-up campaign 3 months later, we will resurvey interested participants to evaluate changes in perception, needs, and recovery behaviors. Survey data will be coupled with local measures of risk, such as the Federal Emergency Management Agency's (FEMA) flood hazard zone data; the National Oceanic and Atmospheric Agency's (NOAA) historical flood and storm event data and the National Aeronautics and Space Administration's (NASA) Regional Climate Model projections; the U.S. Environmental Protection Agency's (EPA) Toxic Release Inventory data; and the U.S. Geological Survey's (USGS) private well location, water use, and water quality data. These data linkages will enable evaluation of possible influences on well owner behaviors; identify locations where well user training may be needed; and identify all threats in target locations to predict other contaminant concerns under similar flood conditions. We aim to improve our knowledge about private well issues throughout the recovery period, and address resource needs relating to well contamination, flooding, and recovery. Survey data will provide the basis for plans to increase well users' resilience against potential future threats.

Objective 3: Determine site-specific hazard proximities, hydrogeologic factors, well construction characteristics, and well user behaviors that increase the likelihood of contamination. Since 1967, the General Assembly of North Carolina has required the completion of well construction records (GW-1 forms), which documents well drilling and construction characteristics (e.g., casing material, screen depth, screen interval). Such records are not typically available or accessible, providing our research team a unique opportunity to evaluate how flow mechanisms into the well system impact the presence of flooding contaminants. Our team will work with residents, local drillers, and health departments to access all available GW-1 forms for private wells sampled in this study. Our hurricane well survey will provide information about well user behaviors and household plumbing information. NC DENR, NOAA, USGS, NASA, and many other agencies have developed federal data repositories which contain a wealth of information on site-specific geologies, weather, flooding patterns, and coal ash impoundment features. These information and data sources, when used together, are ideally suited for evaluating the fate-transport of impoundment contaminants. Using multi-dimensional statistical approaches, fate-transport and hydrogeologic models, and heavy metal fingerprinting methods, we will evaluate and identify key variables that predict the various types of well water contamination that may be observed in participating private wells. This information will provide insight into well water monitoring needs and treatment solutions to address aquifer- or location-specific well water quality issues. In turn, this knowledge will be shared with partners and stakeholders to help state and federal officials prioritize and target what are often limited funds designated for emergency planning, preparation, and recovery.

4. PROJECT MANAGEMENT AND PRIOR NSF SUPPORT

Virginia Tech (Pieper, Rhoads, and Edwards) and Louisiana State University-Health (Katner) have conducted emergency well water sampling in five states following Hurricanes Harvey, Irma, and Matthew and after the 2016 Louisiana floods. The University of North Carolina Institute for the Environment (Gray and George) has been developing community networks in NC well communities surrounding coal ash impoundments for 3 years. Virginia Tech will coordinate the well sampling, water analysis, and reporting; collaborate with health departments to obtain available well construction records; and conduct the multi-dimensional statistical analysis. LSU-Health will provide guidance on the analysis of water quality and well user behaviors and will assist with well resource needs survey analysis. The UNC-IE will coordinate with local community leaders and non-profits to organize the sampling campaign and will distribute the well resource needs survey. The undergraduate and graduate students will be recruited and advised by Pieper and Edwards.

5. BROADER IMPACTS

Unregulated private well users are solely responsible for ensuring the safety of their water from flood-associated hazards. Results from this research will assess the need for state or federal regulatory oversight and monitoring of flood-impacted private wells for both microbial hazards and industry byproducts. Current disaster recovery materials suggest microbial testing provides an assessment of total water quality needs and recommends shock chlorination for post-flood well water treatment. This information needs to be updated to ensure residents are kept informed about the most effective science-based water treatment strategies, and their weaknesses and limitations. Recovery approaches must be tailored to community needs to ensure that their well water testing and treatment behaviors are appropriate and effective for the threats impacting them. Moreover, each community is unique in its needs and access to resources, like internet and translated informational material. Regional climate models have predicted more frequent hurricanes, longer lasting storms, and more severe rainfall and flooding events. It is imperative that public health officials identify and address the unique needs of vulnerable populations, who are often in areas that may be hard for emergency response officials to reach in a timely manner. This research aims to improve natural disaster preparedness and recovery in well-reliant communities by engaging in transdisciplinary research that brings together the perspectives of water quality engineering, hydrogeology, and public health to improve our understanding of well water threats and interventions. The ultimate purpose of this research is to prioritize needs and tailor training to empower populations with the knowledge needed to enhance their resilience and enable autonomous self-reliant water management in times of natural disasters and crises.

6. REFERENCES

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