Potable water hazards and resource needs in private well communities impacted by extreme flooding events

1. PROBLEM STATEMENT AND OBJECTIVES

Texans are starting to recover and rebuild from Hurricane Harvey, which hit the southeast and lower central coast of Texas on August 25, 2017 as a Category 4 hurricane, causing catastrophic storm surges, record-setting flooding, and widespread destruction in 43 counties.[1] Harvey devastated water supplies in an area of Texas that is already historically vulnerable to droughts and water shortages.[2,3] At least 47 public water systems, providing drinking water to hundreds of communities, are inoperable due to power outages, infrastructure damage, or simply being ill-equipped to deal with mass system flooding.[4] Fortunately, these residents are being notified of the unsafe water conditions, with 171 boil-water advisories currently in effect.[4] However, an estimated 12% of the impacted population (870,903 residents) served by private wells are completely responsible for ensuring the safety and integrity of their own water supplies.[5] Safe drinking water regulations do not apply to private wells in Texas or elsewhere in the U.S.

After the Great Louisiana Flood of 2016, where 20 parishes declared a state of emergency,[6] our team hypothesized that flooding events that submerge wells in contaminated water present a public health concern due to widespread well water contamination.[7–10] Working with 113 impacted well users in Louisiana, we learned that even six weeks after the height of the flood, 20% of wells still tested positive for total coliform bacteria. We also took the opportunity to profile occurrence of **opportunistic pathogens (OPs)**, which are known to now be the primary source of tap-water related disease outbreaks in the U.S., but are virtually unexplored in well water.[11–13] Of homes tested for OP DNA markers (n=40), positive detections were 75% for *Legionella* spp., 15% for *L. pneumophila,* and 20% for the brain-eating amoeba *N. fowerli*.[10] Our findings suggested that such OPs are not uncommon in well water and growth is likely promoted when flood contaminated well water stagnates in the system. Moreover, consistent with our concern, public health risks associated with flood-impacted wells have not been addressed. Ninety-five percent of the residents we surveyed in Louisiana noted that they had not received any assistance or information about well water recovery.[8] Participants were worried that their well water was no longer safe and eager for information about testing, maintenance, and treatment.

Leveraging the lessons learned from Louisiana, our team is now mobilizing in response to similar concerns raised by Hurricane Harvey and Irma. We have identified needs through Extension Well Owner Networks and are already responding to numerous requests by residents, providing free testing of hundreds of wells, technical assistance, and other resources to flood-impacted well users. Widespread devastation in Florida is just now being assessed at the time of this proposal – the ongoing warnings by the scientific community of a trend towards increased frequency and intensity of storms, record rains, and flooding in the years to come,[14,15] highlights a public health threat to the underserved population of private well owners that is in critical need of assessment. **Standardized communication and remediation strategies for private wells affected by natural disasters are urgently needed.** Based on our observation and experience, health threats to well owners are not addressed by normal first responders who are appropriately focused on public supplies, creating an under-recognized and unaddressed health risk.

The next few weeks (September-October 2017) is a critical window for the collection of microbial water quality data and characterization of resources and informational needs as residents in Texas and Florida return home and begin to use their private wells. We intend to leverage the ongoing and long-term well water activities of the Extension Well Owner Networks to enable a more comprehensive and systematic evaluation of well water contamination, disinfection protocols and ongoing well owner needs during the one-year period of recovery and rebuilding. The ***three main objectives of this research*** are to: ***1)*** *conduct a multi-state characterization of pathogen risks in private wells after severe flooding events;* ***2)*** *examine short and long-term testing, resource, and recovery needs and practices for diverse range of private*

well owners; and ***3)*** *develop an effective and practical well disinfection protocol that helps to restore contaminated wells to potable water status.* We will achieve these objectives, in part, by leveraging our unique existing partnerships with the US Geological Survey (USGS) and the Virginia Department of Environmental Quality (VDEQ). In addition to validating our original hypothesis following the Louisiana flood of widespread fecal well water contamination and health risk incurred by major flooding events, in this effort we ***will focus on the hypothesis that existing well disinfection protocols do not consistently improve OPs concentrations***.

2. INTELLECTUAL MERIT

There is a dire need for low-cost, practical and effective remediation strategies to ensure access to safe drinking water following natural disasters. However, there has been limited research examining waterborne pathogen hazards in private wells, potential benefits from disinfection, and communication of health risks. These critical research needs have largely gone unaddressed because: a) private wells are unregulated; b) non-formal education and learning activities for well users are not provided in all states; and c) continued reliance on coliform bacteria as indicators of pathogens in well water, when it is now well-known that the primary source of tap-water associated outbreak are OPs which are not derived from feces.[16] This proposal aims to address these three barriers by building on work from a prior NSF RAPID grant.[7–9]

a) **Private wells are unregulated**,[17] which results in varying degrees of vulnerability to environmental health hazards**.** There are 47 million residents (15% of U.S. residents) supplied by unregulated private well systems[5] and state-level surveys suggest that the majority of these systems do not meet the US EPA drinking water standards.[18–20] Coliform bacteria are the most prevalent waterborne contaminant, with some states reporting an incidence rate of 46%.[19] The absence of federal oversight and minimal well stewardship support undermines the US EPA's goals for environmental justice, as well users do not have "the same degree of protection from environmental health hazards and equal access to the decision-making process to have a healthy environment".[21] After Hurricane Matthew in 2016, our team evaluated the accessibility to and availability of well water resources and information in North Carolina (NC).[9] We observed that only 65% of the 85 county-level health departments had testing prices posted on their websites. More problematic was that seven county-level health departments did not have well water information on their websites. Even if testing was available and accessible to county residents, it may not be affordable. The same total coliform analysis costs $25 in Wake County, $50 in Brunswick County, and $200 in Iredell County, NC.[22–24] Similar challenges in access information and environmental protections are evident in other states.[18,25] The well owner surveys and follow-up educational workshops hosted by the Texas A&M AgriLife Extension Service outlined in this proposal will provide insight into the accessibility, availability, and affordability of well water resources and information; characterize the avenues in which residents seek resources and information; and examine disparities in protection from environmental hazards based on factors such as socioeconomics and rurality.

b) **Non-formal education and learning activities for well users are not provided in all states.** Opportunities to participate in educational programs and seek technical assistance from experts are necessary to ensure well stewardship, which legally remains the sole responsibility of well users.[26] When surveying 13 residents in Louisiana during a well disinfection clinic hosted by our team, six residents reported that they were very uncomfortable managing their wells and seven residents had no idea where to find information and resources about doing so.[8] In states with robust Cooperative Extension Service support, Extension has proven to be one of the most successful platforms for engaging, empowering, and educating private well users.[18,19,27–29] Cooperative Extension Service personnel are trusted sources of

science-based information in their communities, including identification of resources for protecting family health and groundwater quality. The Texas Well Owner Network (established 2010; twon.tamu.edu) has educated more than 9,000 well users and sampled more than 7,500 wells across the state. Their well water programs have been valued at an average of $750 per class by attendees, for a cumulative value of $6.75 million.[30,31] Despite such proven benefits, only six states have active Extension well owner education programs. Without the presence of Extension, outreach to this population overburdens already over-extended health departments, non-profits, concerned citizens, or more commonly does not occur at all. This proposed research aims to facilitate development and expansion of Texas and Florida's Well Owner Networks, establish regional collaborations, and illustrate the effectiveness of Cooperative Extension-led Well Owner Network programs. The knowledge gained about the well users' opinions, attitudes, behaviors, obstacles, and resource needs will be shared nationally to assist in recovery after future natural disasters.

c) **Continued reliance on coliform bacteria as pathogen indicators in well water.** Most well water testing campaigns do not directly quantify pathogens, but rely on coliform bacteria to indicate whether fecal pathogens have entered the well.[18–20] Researchers have linked the consumption of coliform bacteria-contaminated well water with cases of acute gastrointestinal illness (AGI). In North Carolina, 99% of drinking water-related emergency room visits for AGI were attributed to contaminated private wells.[32] In Alabama, self-reported AGI symptoms were found to be higher for individuals with fecal coliforms in their drinking water.[33] Even the US Centers for Disease Control and Prevention (CDC) acknowledges that there is a rising trend in the proportion of waterborne disease outbreaks attributed to wells systems since 1971 due to consumption of contaminated groundwater.[34] Thus, microbial contaminated well water poses well-documented public health threats, but the underlying disease-causing pathogens have yet to be fully characterized. Moreover, researchers have noted that the presence of disease-causing pathogens in water are sometimes not correlated at all to coliform bacteria. This is particularly true of OPs, which are native to water systems and not the gastrointestinal tract and therefore are not expected to correlate with fecal indicators. Pathogens in groundwater such as *Norovirus*, *Legionella*, *E. coli* O157:H7, *Cryptosporidium* spp., and *N. fowleri* have been linked to waterborne disease outbreaks,[35] but virtually unexplored in well water. Currently the most common remedial measure for contaminated wells recommended by most private well programs is shock chlorination (i.e., pouring bleach into wells).[36,37] However, the efficacy of shock chlorination is untested and unproven, for both fecal bacteria and OPs. ***Thus, the proposed RAPID will advance understanding of effects of shock chlorination on a representative cross section of pathogens and indicators, as well as on the broader microbial communities, in well water and will take a critical step towards scientifically-proven remediation strategies that can reduce waterborne disease.***

The proposed RAPID effort will characterize well water quality and resource needs in well communities impacted by Hurricane Harvey (Texas) and Irma (Florida). Together with data collected in the aftermath of the Great Louisiana Flood of 2016, our results will aid the development of guidelines for government and public health officials, emergency responders, and well owners regarding well water hazards after floods and resource needs of the well community. This research will have broader impacts in terms of expanding the capacity of Extension Well Owner Networks to provide much needed testing services, educational training, and technical assistance to well users during present and future disasters. More effective intervention strategies will help well owners to protect themselves and their families from flood-associated hazards.

3. APPROACH

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

Objective 1: Conduct a multi-state characterization of pathogen risks in private wells after severe flooding events. Virginia Tech and AgriLife Extension are coordinating a widespread citizen science sampling effort in Texas through the Texas Well Owner Network. AgriLife Extension is distributing our sampling kits through their county-level Extension agents in at least 10 well communities that vary based on socioeconomics and urbanization. These strategies will also be applied with the University of Florida Institute of Food and Agricultural Sciences Extension (IFAS) in response to Hurricane Irma. Virginia Tech will distribute 700 sampling kits in Texas and 500 sampling kits in Florida. Each sampling kit will contain one sterile bottle, sampling instructions, and a well owner survey. Participants will be instructed to collect one water sample from the cold-water tap at normal flow after flushing the system. Residents will return kits to a centralized Extension location for transportation to Virginia Tech. Each participant will receive an email or phone call within 5 days of collection to notify the residents of coliform bacteria results. Within two weeks, each resident will be mailed a water quality analysis along with contact information for AgriLife Extension and Virginia Tech. All water samples will be analyzed for total coliforms, *E. coli*, nitrates, and metals. Water samples from 100 randomly selected wells will receive more comprehensive analysis of pathogens and opportunistic pathogens, including *Legionella spp., N. fowleri, Giardia lamblia, Shigella sonnei,* Shiga-toxin producing *E. coli, Salmonella,* and *Vibrio vulnificus*, as well as an investigation of the broader microbial community by conducting 16S rRNA sequencing. Positive cultures of total coliforms and *E. coli* will be preserved as glycerol stocks for future research on source tracking and antibiotic resistance profiling. Our team will later compare microbial results in three states (Louisiana, Texas, and Florida) in terms of community type (e.g., urban vs. rural, low vs. high income). This assessment will be the most comprehensive multi-state pathogen characterization for flood-impacted microbial health risks of private wells to date. Information gained from this study will provide data and knowledge that enables targeted evidence-based support to private well owners in the aftermath of future natural disasters.

Objective 2: Examine short and long-term testing, resource, and recovery needs and practices for diverse range of private well owners. Specific activities to be conducted include: 1) development of a “plain language” shock chlorination protocol with pictures and simplified instructions; 2) shock chlorination class-related surveys to well owners in flood-impacted areas to measure changes in attitudes and resource needs for well water disinfection procedures; and 3) post-shock chlorination surveys to flood-impacted well owners who disinfected their wells, to further assess obstacles and attitudes on well water disinfection procedures. During the community-wide sampling effort in Texas and Florida, AgriLife Extension in Texas and IFAS in Florida will distribute a survey to impacted private well owners that was developed and used in our prior well recovery project in Louisiana.[8] Private well participants will be surveyed to characterize: 1) resident demographics; 2) extent of flooding and well damage, 3) well construction and design parameters; 4) well water use and consumption patterns, use of water treatment; 5) activities, attitudes, obstacles, and motivations related to well testing, maintenance and disinfection, flood preparation and recovery, and service provision. The survey data obtained from Texas, Florida, and Louisiana will provide a comprehensive, multi-state understanding of resource and recovery needs during natural disasters. In addition, AgriLife Extension will collaborate with local well drillers to host free shock chlorination field-day clinics for well owners in areas impacted by the flood. Surveys will be distributed prior to the clinic, and again after the class is completed to measure changes in knowledge, attitude, and perception of shock chlorination. Residents attending the clinic (up to 300 residents) will also be offered free post-disinfection water testing for coliform bacteria. Samples will be collected by AgriLife Extension and analyzed at Texas A&M. When post-chlorination water samples are collected, residents will be asked to complete a final brief survey to examine difficulties in shock chlorinating the well. Information gained from these activities will be used to characterize knowledge gaps and resource

needs during natural disasters, and help determine whether residents are comfortable shock chlorinating wells.

Objective 3. Develop an effective and practical well disinfection protocol that helps to restore contaminated wells to potable water status. Differences in water chemistry amongst wells and persistent biofilms are two critical factors that may affect the effectiveness of chlorination. We aim to develop an effective chlorination protocol by systematically evaluating these variables by conducting a three-phase study. Phases 1 and 2 will be bench-scale experiments using simulated well water, while Phase 3 will pilot our developed protocol in VDEQ monitoring wells. In Phase 1, our team will determine the impact of various water parameters such as iron, manganese, and organic matter, on disinfection residual during shock chlorination. After developing different well water conditions, varying doses of bleach (5.25% NaClO) will be added and chlorine levels will be measured after for 8, 12, and 24-hours. This effort will improve the understanding of disinfection kinetics (i.e., "CT" disinfection) in well water. In Phase 2, our team will deposit a series of pipe sections (PVC and galvanized iron) into VDEQ monitoring wells and allow biofilms to naturally grow for 1-2 months. These pipe sections with biofilms will then be epoxied in glass jars and conditioned with well water. To simulate the contamination, the test jars will be spiked with *E. coli* and *Legionella* spp. cells. The jars will be shock chlorinated using parameters determined in Phase 1. The effectiveness of shock chlorination will be evaluated by monitoring *E. coli* levels over a three-month period. This effort will determine the effect of shock chlorination on bulk water and biofilm pathogens. In Phase 3, six VDEQ monitoring wells will be flooded with *E. coli* and *Legionella* spp. contaminated water. Three of the wells will be shock chlorinated as determined in Phase 1 and the other three will be allowed to naturally recover. Water quality in these six wells will be monitored over a three-month period, to systematically evaluate the benefits (if any) of shock chlorination that could be recommended to well users.

4. PROJECT MANAGEMENT AND PRIOR NSF SUPPORT

Virginia Tech (Pieper, Rhoads, Dai, Edwards, and Pruden) and Louisiana State University (Katner) have collaborated for two years investigating flood-impacted wells in Livingston Parish, LA. Texas A&M AgriLife Extension (Boellstorff and Gholson) established the Texas Well Owner Network in 2010 and are recognized well water experts in the state. Virginia Tech will coordinate the well sampling and water analysis and spearhead the development of a well disinfection protocol. The Texas A&M team will organize and host well sampling efforts, educational programs, well disinfection clinics in Texas, and will mentor IFAS in hosting well sampling efforts in Florida. Katner and Straif-Bourgeois will advise on well user surveys and community engagement in research activities. The undergraduate and graduate students will be recruited and advised by Pieper, Rhoads, Edwards and Pruden.

5. BROADER IMPACTS

The outcomes of the proposed research will have national, and even international implications, as private well users struggle with access to clean, safe drinking water.[18–20,32–34] Results from this research will inform whether one-time disinfection protocols should be recommended to private well residents for recovery and also provide insight to impediments to disaster recovery. This proposal characterizes flood-impacted communities across two states, while building on our team's past studies and experiences in Louisiana. Together, our collective results will serve to inform well user communities across the U.S. that are impacted by severe floods, a condition which is expected to increase in the coming decades based on current climate models and predictions.[14] This research also highlights environmental and social justice implications, as private wells are not provided the same financial and technical assistance that municipal systems receive. Insights generated by this effort will be framed to inform ongoing national policy discussions regarding safe and affordable water.

6. REFERENCES

1. Gov. Abbott adds 7 Texas counties to Presidential Disaster Declaration. *CBS Dallas/Fort Worth*. 4 September 2017. Available at: http://dfw.cbslocal.com/2017/09/04/gov-abbott-counties-presidential-disaster-declaration/ [accessed September 12, 2017].
2. Amico C.; DeBelius D.; Henry T.; Stiles M. Dried out confronting the Texas drought. *National Public Radio*. 2011. Avaiable at: https://stateimpact.npr.org/texas/drought/ [accessed September 12, 2017].
3. The National Drought Mitigation Center. U.S. Drought Monitor. *University of Nebraska-Lincoln.* Avaiable at: http://droughtmonitor.unl.edu/ [accessed September 12, 2017].
4. Harvey floods left Houston water plant hours away from failure. *CBS News*. 5 September 2017. Available at: https://www.cbsnews.com/news/houston-water-filtration-plant-harvey-flooding-impact/ [accessed September 12, 2017].
5. Maupin M.A.; Kenny J.F.; Hutson S.S.; Lovelace J.K.; Barber N.L.; Linsey K.S. *Estimated use of water use in the United States in 2010*; Circular 1405; U.S. Geological Survey: Reston, VA, 2014.
6. Yan, H. Louisiana's mammoth flooding: By the numbers. *CNN*. 22 August 2016. Available at: http://www.cnn.com/2016/08/16/us/louisiana-flooding-by-the-numbers/ [accessed September 12, 2017].
7. Edwards M.; Pieper K.; Katner A. *Recovery of Well Water Quality After the Great Louisiana 2016 Flood*. *National Science Foundation (NSF) RAPID Response Grant*, $150,919, 10/16-9/17
8. **Katner, A.; Pieper K.J.; Brown K.; Rhoads W.; Edwards M. The Great Louisiana Flood of 2016: Private well owner knowledge, responses, and needs. *Manuscript in development.***
9. Bradley T.; Pieper K.; Katner A.; Lee-Pow Jackson C.; Edwards M. Evaluating disparities in well programs in North Carolina. 27 June 2017. NC Department of Health and Human Services: Raleigh, NC.
10. **Dai D.; Rhoads W.; Pruden A.; Edwards M.; Strom L.; Katner, A.; Pieper K.J. Opportunistic pathogens in flood-impacted well water after Great Louisiana Flood. *Manuscript in development.***
11. Brunkard J.M.; Ailes E.; Robers V.A.; Hill V.; Hilborn E.D.; Craun G.F.; Rajasingham A.; Kahler A.; Garrison L.; Hicks L.; Carpenter J.; Wade T.J.; Bearch M.J.; Yoder J.S. Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking --- United States, 2007—2008. *Morb. Mor. Wkly. Rep.* 2011, *60*, (SS12), 38-68.
12. Yoder J.; Roberts V.; Craun G.F.; Hill V.; Hicks L.; Alexander N.T.; Radke V.; Calderon R.L.; Hlavsa M.C.; Beach M.J.; Roy S.L. Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking --- United States, 2005—2006. *Morb. Mor. Wkly. Rep.* 2008, *57*, (SS09), 39-62.
13. Falkinham J.O. Epidemiology of infection by nontuberculous mycobacteria. *Clin. Microbiol. Rev.* 1996, 9, (2), 177-215.
14. Melillo J.M.; Richmond T.; Yohe G.W. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program. 2014. Available at: http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf?download=1 [accessed 11 September 2017].
15. Shankman S. 6 questions about Hurricane Irma, climate change and Harvey. *InsideClimate News*. 10 September 2017. Available at: https://insideclimatenews.org/news/06092017/hurricane-irma-harvey-climate-change-warm-atlantic-ocean-questions [accessed September 12, 2017].
16. Pruden A.; Edwards M.A.; Falkinham III J.O.; Arduino M.; Bird J.; Birdnow R.; Bédard E.;

Camper A.; Clancy J.; Hilborn E.; Hill V.; Martin A.; Masters S.; Pace N.R.; Prevost M.; Rosenblatt A.; Rhoads W.; Stout J.E.; Zhang Y. *Research Needs for Opportunistic Pathogens in Premise Plumbing: Methodology, Microbial Ecology, and Epidemiology*; Water Research Foundation Project 4379 Final Report; Water Research Foundation: Denver, CO, 2013.
17. Private Drinking Water Wells. U.S. Environmental Protection Agency. Avialable at: https://www.epa.gov/privatewells [accessed September 12, 2017].
18. Swistock, B.R.; Clemens, S.; Sharpe, W.E.; Rummel, S. Water quality and management of private drinking water wells in Pennsylvania. *J. Environ. Health* 2013, *75*, (6), 60-66.
19. Pieper K.J.; Krometis L.H.; Gallagher D.L.; Benham B.L.; Edwards M. Incidence of waterborne lead in private drinking water systems in Virginia. *J. Water Health* 2015, *13*, (3), 897-908.
20. Knobeloch L.; Gorski P.; Christenson M.; Anderson H. Private drinking water quality in rural Wisconsin. *J. Environ. Health* 2013, *75*, (7), 16-20.
21. Environmental Justice. U.S. Environmental Protection Agency. Avialable at: https://www.epa.gov/environmentaljustice [accessed September 12, 2017].
22. Well water testing. Wake County Government. Avialable at: http://www.wakegov.com/water/wells/Pages/watersampling.aspx [accessed September 12, 2017].
23. Private drinking water well testing. Brunswick County Government. Available at: http://www.brunswickcountync.gov/private-drinking-water-well-testing/ [accessed September 12, 2017].
24. Process for drinking water analysis. Iredell County Health Department. Available at: https://www.co.iredell.nc.us/DocumentCenter/Home/View/236 [accessed September 12, 2017].
25. Pieper K.J.; Krometis L.; Edwards M. Quantifying lead leaching potential from plumbing exposed to aggressive waters. *J. Am. Water Work. Assoc.* 2016, *108*, (9), E458-466.
26. Morris L.; Wilson S.; Kelly W. Methods of conducting effective outreach to private well owners- a literature review and model approach. *J. Water Health* 2016, *14*, (2), 167-182.
27. Wojcik D.; Weiss D. Cooperative water quality testing and vulnerability factors for private rural wells in central Indiana. *J. Environ. Health*. 2011, *58*, (8), 16.
28. Richards R.P.; Baker D.B.; Creamer N.L.; Kramer J.W.; Ewing, D.E.; Merryfield B.J; Wallrabenstein L.K. Well water quality, well vulnerability, and agricultural contamination in the Midwestern United States. *J. Environ. Qual*. 1996, *25*, (3), 389-402.
29. Benham B.; Ling E.; Ziegler P.; Krometis L. What's in your water? Development and Evaluation of the Virginia Household Water Quality Program and Virginia Master Well Owner Network. *J. Hum. Sci. Ext*. 2016, *4*, (1), 123-138.
30. Boellstorff D.; Gholson D.; Kalisek D.; Smith J.; Gerlich R.; Wagner K.; Jantrania A.; Mill T. *Statewide Delivery of the Texas Well Owner Network;* Texas Water Resources Institute Technical Report TR-498; Texas State Soil & Water Conservation Board; College State, TX, 2017.
31. Texas Well Owner Network receives AgriLife Extension Team Superior Service Award. AgriLife Today. 12 January 2016. Available at: https://today.agrilife.org/2016/01/12/texas-well-owner-network-ssa/ [accessed September 12, 2017].
32. DeFelice N.; Johnston J.; MacDonald Gisbon J. Reducing emergency department visits for acute gastrointestinal illnesses in North Carolina (USA) by extending community water service. *Environ. Health Perspec.* 2016, *124*, (10), 1583-1591.
33. Stauber C.E.; Wedgworth J.; Johnson P.; Olson J.B.; Ayers T.; Elliott M.; Brown J. Associations between self-reported gastrointestinal illness and water system characteristics in community water supplies in rural Alabama: A cross-sectional study. *PloS one*, *11,* (1), e0148102.

34. Craun, G.F.; Brunkard, J.M.; Yoder, J.S.; Roberts, V.A.; Carpenter, J.; Wade, T.; Calderon, R.L.; Roberts, J.M.; Beach, M.J.; Roy, S.L. Causes of outbreaks associated with drinking water in the United States from 1971 to 2006. *Clin. Microbiol. Rev.* 2010, *23*, (3), 507–528.
35. Bradford S, Harvey R. Future research needs involving pathogens in groundwater. *Hydrogeol J*. 2017, *25,* (4), 931-938.
36. Flood precautions for private water wells. Minnesota Department of Health. 25 Jun 2014. Available at: http://www.health.state.mn.us/divs/eh/wells/natural/floodprecautions.pdf [accessed September 12, 2017].
37. Benham B.; Ling E. *Virginia Household Water Quality Program: Bacteria and other microorganisms in household water*; 442-662; Virginia Cooperative Extension: Blacksburg, VA 2011.