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Strategies to Improve Private-Well Water Quality: A North Carolina Perspective

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Background: Evidence suggests that the 44.5 million U.S. residents drawing their drinking water from private wells face higher risks of waterborne contaminant exposure than those served by regulated community water supplies. Among U.S. states, North Carolina (N.C.) has the second-largest population relying on private wells, making it a useful microcosm to study challenges to maintaining private-well water quality.

Objectives: This paper summarizes recommendations from a two-day summit to identify options to improve drinking-water quality for N.C. residents served by private wells.

Methods: The Research Triangle Environmental Health Collaborative invited 111 participants with knowledge of private-well water challenges to attend the Summit. Participants worked in small groups that focused on specific aspects and reconvened in plenary sessions to formulate consensus recommendations.

Discussion: Summit participants highlighted four main barriers to ensuring safe water for residents currently relying on private wells: (1) a database of private well locations is unavailable; (2) racial disparities have perpetuated reliance on private wells in some urbanized areas; (3) many private-well users lack information or resources to monitor and maintain their wells; and (4) private-well support programs are fragmented and lack sufficient resources. The Summit produced 10 consensus recommendations for ways to overcome these barriers.

Conclusions: The Summit recommendations, if undertaken, could improve the health of North Carolinians facing elevated risks of exposure to waterborne contaminants because of their reliance on inadequately monitored and maintained private wells. Because many of the challenges in N.C. are common nationwide, these recommendations could serve as models for other states. https://doi.org/10.1289/EHP890

Introduction

The introduction of municipal water-treatment systems was one of the greatest public health advances in the U.S. during the twentieth century. A 2005 study of historical public health data in 13 major U.S. cities attributed nearly half of overall mortality reduction, two-thirds of child mortality reduction, and three-quarters of infant mortality reduction between 1900 and 1936 to the installation of municipal water chlorination and filtration systems (Cutler and Miller 2005). The same study estimated that the public health benefits of these investments exceeded total construction, operation, and maintenance costs by a factor of 23 over that period.

Today, communities served by municipal water systems are protected by the Safe Drinking Water Act (SDWA) of 1974 and its subsequent amendments (Tiemann 2014). Under the SDWA, public water systems must ensure that the water they deliver meets health-based water-quality requirements, known as maximum contaminant levels (MCLs), for 91 contaminants. To ensure compliance, utilities must monitor water quality on a monthly or more frequent basis, depending on the size of the system. When monitoring detects contaminants at concentrations exceeding one or more MCLs, the water utility must notify its consumers and take corrective action, such as upgrading its treatment processes. The SDWA provides funds that states can use to assist public water systems with the costs of improvements, and the U.S. Environmental Protection Agency (EPA) offers technical assistance to plan such improvements.

Although most U.S. residents benefit from municipally treated water regulated by the SDWA, the 14% of the population (44.5 million people) who obtain their drinking water from private wells are excluded from these protections (Maupin et al. 2014). An analysis of waterborne disease outbreak data from 1971 to 2006 showed that although outbreaks associated with public water supplies decreased during that period, the number of outbreaks from private well contamination increased (Craun et al. 2010). Evidence suggests that although many private wells deliver water of high quality, a substantial fraction may be contaminated. Past state-level surveys report that 40–58% of private wells exceed at least one SDWA health-based standard, most commonly for bacterial contamination (Swistock et al. 2012; Knobeloch et al. 2013; Pieper et al. 2015). Concerns about children's exposures led the American Academy of Pediatrics in 2009 to issue a policy statement recommending that pediatricians ask families if they obtain their water from private wells to determine whether water contamination could be a source of illnesses (such as gastrointestinal illness and lead poisoning) (American Academy of Pediatrics Committee on Environmental Health and Committee on Infectious Diseases, 2009). The policy statement encourages pediatricians to recommend that parents test and maintain their wells at least annually for coliform bacteria and nitrates along with lead if a child has an elevated blood lead level.

Among U.S. states, North Carolina (N.C.) has the second-highest total population (3.3 million) after Pennsylvania (Figure 1) and the third-highest population percentage (35%, after Maine and Alaska) of residents relying on private wells for drinking water (Maupin et al. 2014). Although this distinction in part reflects that N.C. has the second-largest rural population in the nation (3.2 million), 939,000 private well users (28.4% of the total) are in the six counties classified as urban by the N.C. Rural Economic Development Center due to their high population densities (above 750 people per square mile) (U.S. Geological Survey 2016; The Rural Center 2016). Recent research has revealed associations between N.C. private-well water quality

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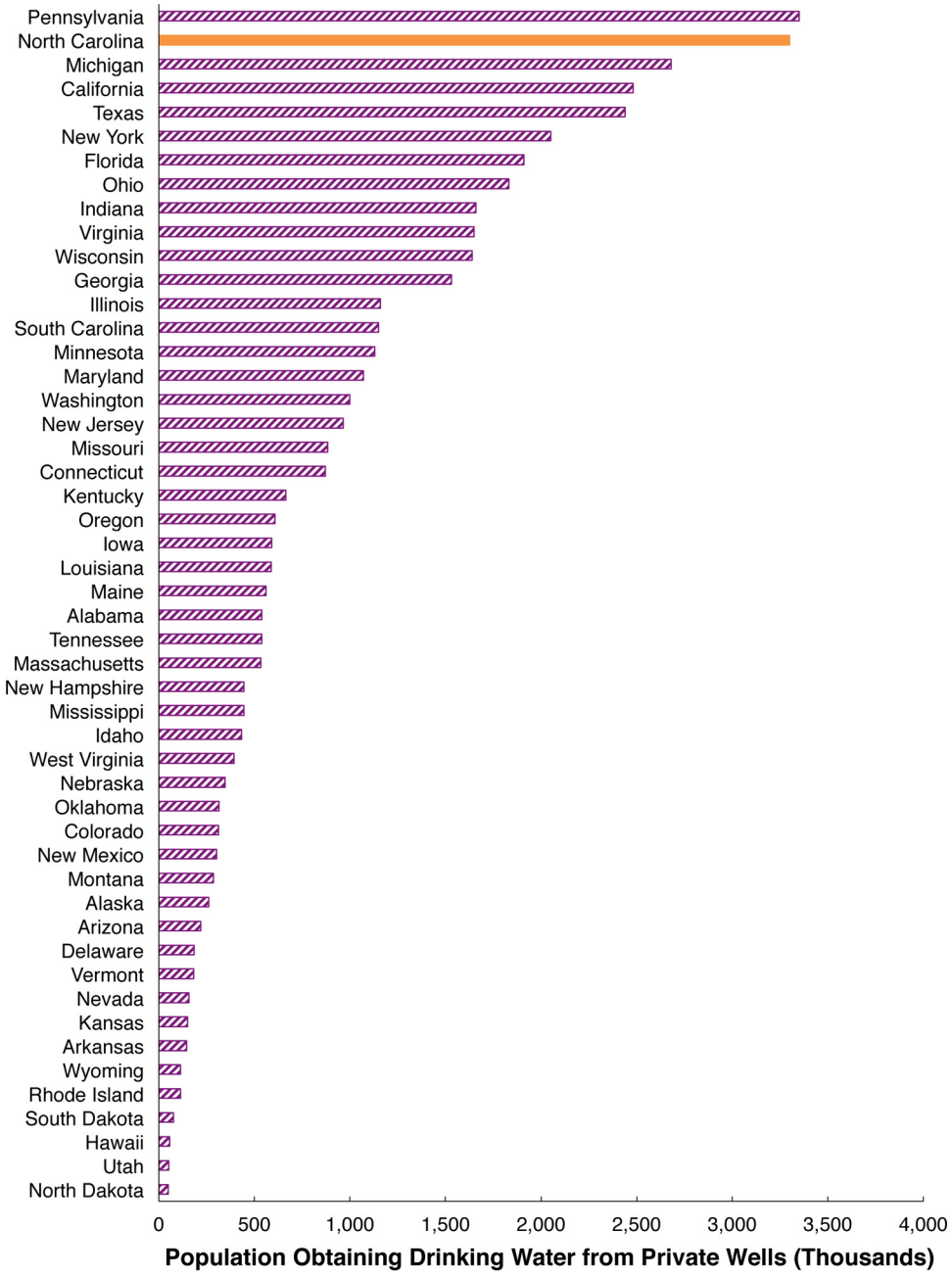

Figure 1. Among U.S. states, North Carolina has the second-largest number of people relying on private wells for their drinking water. Data source: Maupin et al. 2014.

and health risks. For example, our recent research demonstrated that 99% of N.C. emergency-department hospital visits for acute gastrointestinal illness associated with exposure to waterborne microbial contaminants are attributable to private-well contamination (DeFelice et al. 2016). Other recent research has linked elevated concentrations of metals in N.C. private wells to the risk of birth defects (Sanders et al. 2014). With such high incidence of reliance on private wells and with recent evidence of significant health risks for some private-well users, N.C. offers a useful microcosm in which to analyze challenges and solutions to ensuring that private wells deliver safe drinking water.

Recognizing the need for new solutions to N.C.'s private-well water quality challenges and the potential broader national relevance of these challenges, the N.C. Research Triangle Environmental Health Collaborative (Collaborative) convened a summit, "Safe Water from Every Tap," on 26–27 October 2015, to identify and discuss strategies to reduce health risks from private-well water contamination. This paper provides context to understand obstacles to maintaining private-well water quality in N.C. and summarizes major recommendations from the Summit. Although the Summit focused on N.C., many challenges to private-well stewardship are common nationwide. In the discussion, we highlight the broader relevance of the Summit recommendations to other states.

Methods

The Summit was organized by the Collaborative's 14-member executive committee, which is chaired by former N.C. Public Health Director Leah Devlin and Department of Environmental

Quality (DEQ) Secretary William Ross (Table S1). To represent a variety of perspectives, the committee invited representatives of county, state, and federal agencies, public health practitioners, academic scientists, nonprofit community-based organizations, elected officials and policy makers, industry and water utility representatives, and environmental and public health consultants with knowledge of private-well water quality challenges. In all, 111 participants attended (Figure S1; Table S2). Several participants (e.g., from the Southeast Rural Community Assistance Project and community-based organizations) represented constituencies of private-well owners. In addition, other attendees served a dual role representing their organization (such as the N.C. Division of Public Health) and as a current or former private-well owner.

To facilitate interactive discussions and cross-disciplinary exchanges, the Summit alternated between expert plenaries and small work-group breakout sessions. Participants registered for one of four work groups on the themes of (1) private-well owner education, (2) governance and policy for private wells, (3) groundwater pollution prevention, and (4) user-friendly technology for private-well monitoring and maintenance. Participants remained in the same group throughout multiple breakout sessions to facilitate the development of within-group recommendations.

The plenary on the Summit's first day featured presentations on federal and state programs related to private-well water quality and a panel discussion including communities affected by private-well contamination. During the afternoon, work groups met separately to define private-well water quality challenges related to their group's theme. All participants then reconvened to discuss and debate challenges highlighted by each group and to identify common themes. The second day followed a similar structure, with a morning plenary presenting innovative technologies for managing decentralized water supplies, followed by work-group breakout sessions to identify and prioritize solutions to the challenges identified on the first day. During the last plenary, participants integrated and prioritized common themes and recommendations from the four groups. The executive committee further refined recommendations through e-mail feedback after the Summit.

Results

Participants in the "Safe Water from Every Tap" Summit engaged in a consensus process to identify challenges to and recommendations to improve N.C. private-well water quality. Participants decided to focus their recommendations on four critical challenges:

1. The N.C. population relying on private wells is poorly characterized. Consequently, the N.C. Division of Public Health and county health departments lack the information they need to target households for risk communication, technical assistance, or other interventions.
2. Racial discrimination in the establishment of municipal boundaries excluded some peri-urban N.C. communities from public water service. As a result, these communities rely on private wells despite their proximity to municipal water lines and are at risk of exposure to well-water contaminants brought about by high population densities.
3. Many N.C. private-well users lack the knowledge and/or resources needed to routinely monitor and maintain their well water. These well users are therefore at risk of exposure to contamination that could be detected and removed if the households were part of a well-managed and regulated community water system or if household treatment were installed and properly maintained by the user.
4. Programs to protect private-well water quality and to support homeowners in managing their wells are fragmented across state and county agencies. These programs lack the resources to help private-well owners ensure that their drinking water meets recommended health-based standards, such as the standards that community water supplies are required to meet under the U.S. SWDA.

Participants proposed 10 high-priority recommendations to address these challenges. Table 1 summarizes the recommendations and proposes a time sequence for implementation. The following sections provide context to understand the need for these recommendations.

Challenge 1: Private-Well Population is Poorly Characterized

Ideally, county health departments would send regular communications to private-well owners reminding them to test their wells each year and providing information about what to do if tests revealed water-quality problems. However, neither the individual counties nor the state has a complete database with addresses of private-well owners. As a result, delivering these messages or other interventions to help well owners poses a major challenge.

The most comprehensive nationwide private-well population inventory (the basis for Figure 1) was compiled by the U.S. Geological Survey (USGS) (Maupin et al. 2014). Although the USGS data are useful in identifying counties with high incidence of reliance on private wells, these data lack geographic locations of private wells. The USGS data were developed by obtaining data regarding the size of the population served by each public water-supply system in each county and then subtracting the total from the county population.

Several other data sources could help to identify private-well locations. Potential sources include utility service area maps, water pipeline maps, N.C. private-well permitting and testing databases, and the U.S. Census. However, our investigations have shown that none of these sources provides complete and accurate spatial coverage (Leker 2015). GIS files containing utility service-area boundaries are often overly inclusive, for example, showing the entire county as being included in the water utility's service area even in counties where a large population relies on private wells. Detailed water-utility maps that show water-main locations have been difficult to obtain due to post-9/11 security concerns. To our knowledge, the most recent map of water-main locations, compiled by the N.C. Rural Economic Development Center, includes only 75 of the state's 100 counties and has not been updated since 1997 (Leker 2015). Even when utility pipeline maps are publicly available, they indicate water-main locations but not addresses of households served. We are aware of neighborhoods that are bisected by water-service lines but that contain households unconnected to those lines (Heaney et al. 2013; MacDonald Gibson et al. 2014).

Statewide well permitting and testing databases are another potential source of private-well-owner addresses. Since 1967, N.C. has required permits for all new drinking-water wells. However, rather than being issued and tracked by the state, permits are issued and filed by counties in paper copies. Some counties (for example, Chatham http://www.chathamnc.org/index.aspx?page=1887) have digitally scanned some of its permits and are beginning to construct databases, but a complete, statewide inventory is unavailable. Furthermore, wells constructed before 1967 are exempt. Since 1 January 2009, N.C. has required that all new wells must be tested for selected contaminants; county health departments collect water samples and send them to the N.C. State Laboratory of Public Health. The locations of tested wells could be used to map locations of households that rely on

Table 1. Ten recommendations for protecting the health of households relying on private wells.

Recommendation	Responsible organization(s)	Timing
Challenge 1: Private Well Population Is Poorly Characterized		
1. The Division of Public Health (DPH) or Department of Environmental Quality (DEQ) should collect and coordinate all available state and county data relevant to characterizing private well locations.	North Carolina (NC) DPH or DEQ	Immediate
Challenge 2: Racial Disparities Have Perpetuated Reliance on Private Wells in Some Communities		
2.1. The General Assembly should authorize and fund a study to identify areas underserved by community water and sewer service that could be connected to existing municipal water lines.	NC General Assembly	After recommendation 1 (since information on well locations is required)
2.2. The DPH, DEQ, or a private foundation should fund a preliminary state-wide analysis of the capital costs of extending municipal water service to underbounded neighborhoods, and areas in need of service extension should be prioritized.	NC DPH, DEQ, and/or private foundation	After recommendation 2.1 (since data on locations of underserved neighborhoods are required)
Challenge 3: Many Private Well Users Lack Knowledge and Resources to Routinely Test and Maintain Their Wells		
3.1. The DPH should develop targeted marketing campaigns to promote private well testing and maintenance.	NC DPH	Immediate
3.2. An appropriate NC state agency or foundation should fund a study to analyze options for providing financial assistance to low-income private well users to afford the costs of well monitoring and maintenance.	NC DPH, DEQ, and/or private foundation	After recommendation 3.1 (since marketing campaign results can reveal needs for assistance)
3.3. DPH, DEQ, or a private foundation should support a study of options for promoting the development of affordable private well contract maintenance services, in which private system users pay subscription fees for routine well maintenance and testing and for assistance in installing and maintaining household water treatment systems where necessary.	NC DPH, DEQ, and/or private foundation	After recommendations 1 and 3.2 (since well location data can assist in planning and marketing data can reveal needs)
3.4. The General Assembly should allocate resources to DEQ to build an interactive mapping tool that well owners and health departments can use to identify wells at risk of contamination.	NC General Assembly	After recommendation 1(since well location data are required)
3.5. The DPH should update and upgrade its existing web sites to assist homeowners in finding state-accredited water testing labs, selecting contaminants for monitoring, collecting samples, interpreting test results, and selecting water treatment technologies.	NC DPH	Immediate
3.6. The DPH or DEQ should create a state-wide network of professionals that provides information and training on private well issues.	NC DPH or DEQ	Immediate
Challenge 4: Private Well Programs Are Fragmented and Insufficiently Resourced		
4. The NC General Assembly should commission a study of the adequacy of existing private well regulations and programs.	NC General Assembly	Immediate

private wells, but only for wells constructed since 2009. In addition, because test results are typically submitted as paper copies, adequate resources would need to be provided to the N.C. State Laboratory of Public Health to convert all of the paper forms to a searchable database.

A final potential information source on N.C. private well locations is the U.S. Census. Through 1990, the Census collected household-level data on drinking-water sources. However, this question was classified as nonmandatory after 1990 as part of a process of streamlining the Census questionnaire (U.S. Census Bureau 2009). The streamlined 2000 Census, unlike its 1990 predecessor, excluded all questions that were not required by federal law. Local, county, or state governments can request that the U.S. Census Bureau conduct a special census that could include questions about water and sewer access (U.S. Census Bureau 2015). However, the requesting governments must pay for this service, and the U.S. Office of Management and Budget must approve the questions.

In summary, the Summit participants identified lack of address-level and demographic data on N.C. households relying on private wells as a critical barrier to developing outreach to residents and other programs to ensure adequate water quality. To address this barrier, participants recommended the following:

Summit recommendation 1. The N.C. Division of Public Health (DPH) or DEQ should collect and coordinate all available state and county data relevant to characterizing the locations of private wells. Data sources may include well-construction and well-abandonment forms, N.C. State Laboratory of Public Health well-sampling records, and municipal water-pipe maps. Gaps in the inventory should be identified, and a program initiated (possibly including door-to-door efforts in targeted communities) to fill the gaps. Although this effort should be coordinated with local health departments, these departments are insufficiently resourced to bear the burden of data collection; therefore, state funding and coordination are essential to success. If completed, such a database could serve as a model for other states that also lack comprehensive, centralized data on private-well locations and characteristics.

Challenge 2: Racial Disparities Have Perpetuated Reliance on Private Wells in Some Communities

Some peri-urban neighborhoods in N.C. are excluded from nearby water service despite their proximity to municipal water lines. Due to high population and septic-system densities, wells

in such neighborhoods may be at increased risk of contamination (Borchardt et al. 2003; Stillo and MacDonald Gibson 2017).

Several N.C. case studies have documented African American communities on the borders of or surrounded by towns and cities that are excluded from nearby municipal services. For example, a 2004 case study documented that the Mebane City Council over its history had systematically drawn discontiguous municipal boundaries in order to exclude four black communities (Johnson et al. 2004). Although one of the communities neighbored the municipal sewage-treatment plant, neither this community nor the other three had access to municipal water or sewer service. Exclusionary zoning practices continued in Mebane through at least the 1990s as the town annexed satellite parcels slated for high-income residential development and continued to exclude the historically black communities. In 2005, the *New York Times* reported on a similar predicament affecting African American communities around Pinehurst, site of the U.S. Open Golf Tournament that year (Dewan 2005). In 2013, Heaney et al. documented exclusion from municipal services in the Rogers Road community neighboring Chapel Hill and Carrboro (Heaney et al. 2013). In 2014, researchers found statistical evidence of racial exclusion from water service in extraterritorial jurisdiction (ETJ) areas of Wake County (MacDonald Gibson et al. 2014). These ETJ areas border or are surrounded by municipalities, and the municipalities are allowed to control zoning decisions there, but they are not required to provide municipal services (although they may elect to do so). We found that in Wake County ETJ census blocks, every 10% increase in the black population proportion increased the odds of exclusion from municipal water service by 3.8% (MacDonald Gibson et al. 2014). In addition, we found a high prevalence of bacterial contaminants (29% of samples tested positive for total coliform bacteria and 6.4% were positive for *Escherichia coli*) in household drinking water in these excluded communities, and showed an increased risk of visiting an emergency department for acute gastrointestinal illness (Stillo and MacDonald Gibson 2017).

Summit participants agreed that improving drinking-water quality in peri-urban households still relying on private wells should be a high priority due to their proximity to regulated municipal water supplies and the increased risks to water quality from the relatively high population densities. Our prior research interviewing 25 key informants and 18 private-well owners in ETJ areas in four N.C. counties (Wake, New Hanover, Hoke, and Transylvania) explored the major barriers to connecting to municipal services (Naman and MacDonald Gibson 2015; Fizer 2016). Cost was the most prominent concern for officials, who would need to authorize service extensions, and for well owners. For example, a town mayor told us, "We've got a section in town here that does want to be annexed. The [city] will not do it. We did a study on it. . . . The payback was like 115 years" (Naman and MacDonald Gibson 2015). Homeowners doubted their ability to pay for connections to municipal water systems and to afford monthly water bills. For example, one private-well owner said, "But I know I am going to have to [deal with well water the rest of my life] because I cannot afford to have the city tapped in . . . . It is like five houses on this street that we all have well water and we would like to have city water" (Fizer 2016). Some homeowners also communicated that they preferred their well water because of its flavor and odor, even in households where we detected bacterial contaminants (Fizer 2016; Stillo and MacDonald Gibson 2017). In other communities, homeowners may desire access to municipal supplies but fear advocating for such services due to fear that public health officials could condemn their land if their septic system is failing (Naman and MacDonald Gibson 2015). Some communities (such as in Mebane) have advocated for municipal service extensions for decades, but their requests have been continually denied or only partially fulfilled (Johnson et al. 2004; Wilson et al. 2008).

As a start toward improving the safety of drinking water in peri-urban areas historically excluded from nearby municipal water service, Summit participants recommended that the state undertake two studies:

Summit recommendation 2.1. The N.C. General Assembly should authorize and fund a study to identify ETJ areas underserved by community water and sewer service that could be connected to existing municipal water lines. The study should evaluate the benefits and drawbacks of extending community water services and should consider other potential mechanisms (for example, designating a responsible environmental or public health management entity) to ensure drinking water quality.

Summit recommendation 2.2. A preliminary statewide analysis of the capital costs of water-service extensions to underserved ETJ communities should be completed, and areas in need of service extension should be prioritized. Existing and potential innovative options for financing capital costs of service extensions should be identified. This analysis should also examine the feasibility of establishing third-party options to administer the funds and mechanisms to help low-income communities afford monthly water and sewer bills. In addition, this effort should evaluate the legislative changes to annexation necessary for municipalities to extend services and to assess secondary impacts of infrastructure extension (e.g., changes in impervious surfaces, economic development, and public health).

Challenge 3: Many Private Well Users Lack Knowledge and Resources to Test and Maintain Their Wells

Statewide private-well testing data indicate that few N.C. well owners monitor their water quality on a routine basis. Although N.C. has required testing of new wells since January 1, 2009, the number of wells tested illustrate this program's limited reach. Over the five-year period 1 January 2009–31 December 2013, the N.C. State Center for Health Statistics reported that 16,138 well-water samples statewide had been tested. Assuming each sample represents a distinct well, only 1.2% of all 1.3 million self-supplied domestic water wells were tested. Our interviews with 18 private-well owners in Wake County found that one (5.5%) tested at the recommended annual frequency, another two (11%) tested every 2–3 y, two (11%) tested every 4–5 y, and the rest (72%) tested less than every 5 y or not at all (Fizer 2016). Among this group, only eight (44%) reported ever taking any action to maintain their wells. All 18 interviewees thought they could detect contaminants through taste, odor, and appearance. All also mentioned costs as a barrier to testing. In Wake County, bacteriological analysis costs $25 per sample, and analyses for single chemicals or chemical groups cost $20–105 per sample with additional sample collection fees of $50 for some contaminants.

Even if well owners do monitor their water quality, the costs of home-treatment systems may pose a barrier to taking action when contaminants are detected. Purchase and installation of a whole-house water filter to remove contaminants typically costs hundreds to thousands of dollars, depending on the type of unit. Point-of-use treatment devices, which treat water for only a single tap, are less costly (with purchase costs as low as $25), but they do not provide complete coverage of all faucets. Some Wake County well owners we interviewed mentioned cost as a barrier to the purchase of a treatment system (Fizer 2016). One homeowner reported that her water had been tested and contaminants found, but that she could not afford a treatment unit, so she stopped drinking the water and only uses it for nonpotable purposes.

To promote monitoring and maintenance of private wells, Summit participants recommended the following new initiatives:

Summit recommendation 3.1. The DPH should develop marketing campaigns to promote private well testing and maintenance. Social marketing campaigns could target new parents (for example, through prenatal classes and medical practices); child care centers; K–12 schools; recipients of Women, Infants, and Children program benefits; health care providers; mobile health clinics; Medicare recipients; and faith-based groups and homes in areas known to be at risk of contamination (especially those with wells pre-dating mandatory new-well testing). The campaigns could include distribution of drinking-water test kits with instructions about where to send the kits for analysis and links to a website to help homeowners interpret test results (see recommendation 3.5). The campaigns also could include information about contamination prevention, such as proper septic-system maintenance.

Summit recommendation 3.2. A state agency or foundation should fund a study to analyze options for providing financial assistance to low-income private well users to afford the costs of private-well monitoring and maintenance. Existing programs, supported by federal and state governments and private organizations, that help low-income households pay their energy bills could serve as models for similar programs for private-well owners. For example, the N.C. Department of Health and Human Services operates a federally funded Low-Income Energy Assistance Program to provide one-time payments for households unable to pay their winter heating or summer cooling bills (North Carolina Department of Health and Human Services 2016); many counties and energy utilities offer similar programs (Duke Energy, 2017).

Summit recommendation 3.3. DPH, DEQ, or a private foundation should support a study of options for promoting the development of affordable private-well contract maintenance services, in which private-system users pay subscription fees for routine well maintenance and testing and for assistance in installing and maintaining household water-treatment systems where contamination is identified. These services could also include septic-system maintenance in areas where septic systems threaten private-well water quality.

Summit recommendation 3.4. The N.C. General Assembly should allocate resources to the DEQ to build an interactive mapping tool for use by well owners and county health departments in identifying wells at risk of contamination. Such a tool could be modeled after the U.S. EPA's Drinking Water Mapping Application for Protecting Source Waters. Other state agencies should be required to contribute relevant data. Adequate resources should be provided to enable the DEQ to fill gaps in data necessary to delineate areas where private wells are at highest risk of contamination and to monitor contaminant trends.

Summit recommendation 3.5. The DPH should update and upgrade its existing websites to assist homeowners in finding state-accredited water testing labs, selecting contaminants for monitoring, collecting samples, interpreting test results, and selecting water-treatment technologies. The website should be linked to the interactive mapping tool to be developed by the DEQ. It should include a comprehensive catalog of currently available, easily used point-of-use and whole-house treatment technologies and an interactive decision tool to help homeowners select an appropriate technology. The website could be modeled on New Hampshire's Be Well Informed and Pennsylvania's Drinking Water Interpretation Tool. One feature of these sites is that they enable users to enter their measured water-quality parameters. The sites then generate a customized interpretation, including information about whether the parameters were above or below the SDWA MCLs and links to more information. The New Hampshire tool also provides information about possible treatment options and discusses the adverse health effects of each parameter.

Summit recommendation 3.6. The DPH or DEQ should create a statewide network of professionals who provide information and training on private-well issues. This network could host workshops and presentations on such issues. Professionals could be encouraged to participate by offering continuing-education credits. Use of a webinar format would facilitate communication among agencies and universities and minimize travel and financial burdens. This network could be linked to the U.S. Centers for Disease Control (CDC) and Prevention's Private Well Community of Practice, which hosts a bimonthly webinar highlighting cutting-edge research addressing water and health problems in private wells throughout the United States.

Challenge 4: Private-Well Programs are Fragmented and Insufficiently Resourced

As previously mentioned, the SDWA does not regulate private wells. The N.C. legislature has enacted several laws governing various aspects of well construction, along with programs to protect groundwater sources tapped by private wells (Table 2). In addition, county health departments provide well testing services upon request, and some offer reduced-cost testing for low-income households. However, as Table 2 illustrates, administration of these programs is fragmented across agencies. No single organization is in charge of helping private-well owners ensure the safety of their drinking water.

To improve coordination across state and county programs and evaluate the adequacy of existing programs, Summit participants recommended the following:

Summit recommendation 4. The N.C. General Assembly should commission a study of the adequacy of existing private-well regulations and programs. The study should evaluate well-construction standards, consider requiring operating permits for private wells on rental properties, assess the value and feasibility of requiring well testing at the time of property resale, and evaluate the potential for support programs for low-income well owners. It should also evaluate the adequacy of DPH and DEQ staffing to track contamination and maintenance issues and provide technical assistance to well owners and local health departments.

Discussion

The 2016 NC Environmental Health Collaborative Summit highlighted four principal barriers to ensuring that N.C. residents who rely on private wells receive drinking water of sufficient quality to protect their health. These barriers are (1) lack of a comprehensive database of private-well locations, (2) exclusion of some peri-urban minority communities from municipal services, (3) lack of well owner compliance with recommendations for monitoring and maintaining their wells, and (4) a fragmented system of regulations and programs for supporting private-well owners.

Other states face similar challenges. Elsewhere, as in N.C., databases with locations of private-well owners are incomplete. For example, in Oregon, private-well testing data are collected on paper forms that are not routinely digitized or collected by a central state agency (Hoppe et al. 2011). Texas began digitizing private-well construction reports in 2003, but records of wells built before then are not included in the state's database, although scanned, portable document files of prior hand-written well reports are available (Texas Water Development Board 2016). The U.S. CDC has recognized the lack of data on private-well locations and has established a Private Well Initiative, the first goal of which is to answer the question, "Where are the

Table 2. Existing private well protection programs in North Carolina (NC).

Program	Description	Implementing agencies
Permitting, inspection, and testing of new wells	Since July 1, 2008, every new private drinking water well must be permitted, inspected, and tested by the local health department. Testing includes analysis for arsenic, barium, cadmium, chromium, copper, fluoride, lead, iron, magnesium, manganese, mercury, nitrates, nitrites, selenium, silver, sodium, zinc, pH, and bacterial indicators. Follow-up testing after construction is not required.	Local health departments, with oversight of Division of Public Health (DPH)
Well construction standards	Every well must be constructed to meet statewide minimum standards for location, casing, grouting, and screening. Some counties have enacted more stringent standards.	Local health departments in conjunction with DPH
Well contractor certification	Any person engaged in well construction, installation, repair, or abandonment must be certified by the NC Well Contractor Certification Commission. Certification is based on a written exam, work experience, and field observation.	NC Well Contractor Certification Commission (staffed by DPH)
Voluntary well testing	Local health departments offer low-cost well testing upon request.	Sampling by local health departments. Analysis by the State Laboratory for Public Health, certified private lab, or local health department.
Health risk evaluations	DPH provides recommendations for well water use based on results of the mandatory sampling of new wells or voluntary sampling.	DPH and local health departments
Groundwater classifications and quality standards	NC law has established drinking water as the best intended use for groundwater, and the NC Department of Environmental Quality (DEQ) has developed standards to protect the resource for that use. Violations trigger corrective action, with restoration to potable standards as the goal (though alternative standards are possible).	DEQ
Bernard Allen Emergency Drinking Water Fund	This fund pays for notification of well owners, water sampling, and alternative water sources near known contamination for qualifying individuals when no responsible party or other fund is available.	DEQ-Division of Waste Management

Note: Table developed by E. Kane, hydrogeologist, Wake County Environmental Services Department.

unregulated drinking water systems in the U.S.?" (Backer and Tosta 2011). However, to date, a national database of well locations does not exist.

Racial disparities in access to nearby community water services also have been documented elsewhere. Aiken was the first to describe the use of selective annexation to exclude black communities from municipal boundaries and the services offered to municipal residents (Aiken 1987). In a 1987 study in the Mississippi Yazoo Delta, he found that towns incorporated white neighborhoods at the urban fringe and excluded similar African-American neighborhoods to dilute the voting strength of African-American citizens. He referred to such practices as "municipal underbounding." In a 2007 analysis of U.S. Census data from 1,992 towns and communities in eight southern states, Lichter found that towns with high white population percentages were significantly less likely to annex and provide water and other municipal services to African-American municipal fringe areas than they were to annex predominantly white fringe neighborhoods (Lichter et al. 2007). Beyond the southern plantation crescent, recent research has documented racial underbounding in the Texas Lower Rio Grande Valley (Durst 2014) and California's Central Valley (Ranganathan and Balazs 2015). In their article on the Central Valley, Ranganathan and Balazs referred to underbounded communities as "a piece of the Third World in the First World."

Lack of routine monitoring of water quality in private wells is a nationwide problem as well. For example, a 1998 survey of 244 upstate New York well owners found that 47% had never tested their water (Schwartz et al. 1998). A 2009 Wisconsin survey of 2,600 well owners found that although 67% reported having ever tested their water, only 24% had done so in the past year (Knobeloch 2009). A 2012 study of 622 Pennsylvania well owners found that 30% had never tested their water, and 44% had tested it just once, usually only for coliform bacteria (Swistock et al. 2012). All of these studies found that well owners were largely unaware of testing recommendations (Schwartz et al. 1998; Swistock et al. 2012). For example, in Wisconsin, 45% of 2,600 survey respondents said they did not know what to test for, and 42% said they did not know where to send samples for analysis (Knobeloch 2009). Just as in N.C., the Wisconsin study revealed the misperception that drinking water contaminants can be detected through sensory perception: 82% of those who had not tested their water said their reason for not testing was that the water "tastes and looks fine." Financial barriers are an impediment to testing elsewhere, too. The New York study found that survey respondents living in low-income/low-education counties reported lower testing prevalence (41%) than respondents living in high-income/high-education counties (64%) (Schwartz et al. 1998). Similarly, the Wisconsin study reported that 33% of families earning less than $20,000 per year had ever tested their well water, and 71% of families earning more than $75,000 per year had done so (Knobeloch 2009). A New Hampshire study found that among those who reported never having tested their well water for arsenic (widespread in New Hampshire's geologic

formations), 25% said cost was the major barrier to testing (Borsuk et al. 2014).

Fragmentation of programs to support private-well owners also occurs nationwide. Some states, such as Texas (Texas Commission on Environmental Quality 2014) and Pennsylvania (Swistock et al. 2012), do not regulate private wells at all. Among states with regulations, programs and responsible agencies vary substantially, with the latter ranging from state or local health departments to water resources agencies, natural resources departments, environmental protection agencies, and various land grant university extension services (Rogan and Brady 2009). A few states have stringent testing requirements. For example, New Jersey, Rhode Island, and Oregon require well-water testing at time of resale of residences (Fox et al. 2016), although the testing requirements and enforcement of the laws vary substantially in these three state programs. Like N.C., many states have well-construction standards and contractor-certification or licensing requirements, but these requirements can vary substantially by state. For example, in California, local water agencies or water districts determine required minimum depths for grouting between the upper portions of the borehole and the well casing, whereas other states establish mandatory state-wide minimum depths (California State Water Resources Control Board 2015). Some states require the use of pitless adapters (which allow the pipe delivering water from the well to the home to be buried below the frost line), but other states do not.

One consequence of the lack of federal regulations and the fragmentation across state programs is that private-well owners lack access to the financial support available to regulated public water systems. The SDWA established a low-cost loan program for water utility infrastructure improvements that provided $13.1 billion in federal investments through 2009 (Copeland and Tiemann 2010). Prior to the SDWA, communities with municipal systems also were eligible for grants and loans under the 1972 Clean Water Act and its predecessors through programs that Copeland and Tiemann called "the largest nonmilitary public works programs since the Interstate Highway System" (Copeland and Tiemann 2010). During the Reagan Administration, the amount of federal funding for water and sewer infrastructure dropped substantially and shifted from grants to loans (Copeland and Tiemann 2010). Notably, much of the period of active federal investment in clean water infrastructure coincided with the period of systematic exclusion of southern African-American communities from municipal services, denying these communities access to federal benefits afforded to similar white communities.

Although programs to support private-well users, study the demographics of well users, and record water quality characteristics vary nationwide, prior research indicates that the challenges to private-well stewardship identified for N.C. are common nationwide. As a result, the Summit recommendations may be useful in other states that are grappling with challenges to supporting private-well owners in maintaining safe drinking water. Indeed, a report from a recent CDC workshop on private wells emphasized the need for "building an infrastructure for stewardship" of private wells nationwide (Fox et al. 2016).

One challenge not discussed by Summit participants is the effects of drought on private wells. N.C. has a relative abundance of water, with average rainfalls ranging from around 45–60 in per year, depending on region (mountain, piedmont, or coastal plain) (National Oceanic and Atmospheric Administration 2016). In contrast, rainfall in arid regions is a fraction of this amount, leaving private-well users at risk of running out of water. For example, case studies of Latino communities around Fresno, California, where average annual rainfall is 11.5 in, have reported instances of private wells running dry, forcing residents to purchase water from local grocery stores (Pannu 2012). In our discussions with N.C. private-well owners, we have encountered households that were forced to haul water from grocery stores or gas stations because of well components freezing during winter. However, water quantity did not emerge as a major concern at the Summit, likely due to the general abundance of water in N.C. on average.

Conclusions

Because N.C. is an economically and racially diverse state, with land uses ranging from highly developed urban and industrial areas to rural crop and livestock production, the challenges to maintaining private-well water quality in this state are likely to reflect those in other states as well. The Collaborative Summit recommendations presented in this article should apply not only in N.C., but also in other states struggling with similar issues related to protecting the health of populations that draw their water from private wells. Indeed, N.C. could serve as a test bed for innovative private-well protection programs, such as contract maintenance, financial support, data system improvement, and outreach initiatives that could ensure private-well water quality and better health for all residents.

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