Well Owner Disinfection Decisions Affected by Pathogenic Contamination

Abstract

The cost of protective well testing and disinfection for safe private domestic water supply is substantially less than medical treatment costs and lost income from severe infection from drinking water of wells with pathogenic contamination. A useful aid for well owners is a comparison of the costs of health protective steps of well disinfection to significant medical costs of long-term illness and possible death. Recent events of flooding from hurricanes have affected microbial quality of groundwater in portions of the eastern and mid-western United States and elsewhere. Microbial contamination of wells can result from: waste lagoon seepage, contaminated floodwater, poorly operating septic tank, sewage overflows, broken or leaking sewer line, improperly designed landfill, stormwater runoff from woodlands, pastures, feedlots and grazing animals (wild or domestic), backflow from contaminated sources, suction in water lines drawing in soil water at the pipe joints and through faulty sanitary seals in the well system. Well disinfection is considered effective in destroying pathogens in wells. Health effects of diarrhea, cramps, nausea, vomiting, headaches and even death can result from salmonella poisoning, giardiasis, hepatitis, and other waterborne disease, all of which have been observed in waterborne illness in the United States and around the world. If well contamination is suspected, excluding the cost of premature death, the potential avoided-cost savings (benefit) for a severe microbial infection is estimated to be $11,910 - $12,690 for treatment, hospitalization and lost wages in the United States compared to the well safety cost of $570 to $1,395 for well testing and disinfection. If multiple residences share a well that becomes infected, the disinfection cost to each residential owner goes down while the benefit of avoided medical expenses and wage loss increases proportionately with each individual potentially affected. Ideally, these losses from illness can be avoided or minimized with regular well inspections to address the condition of the well and the continuing safety of its water. The potential human cost of medical treatment and lost income if a severe infection occurs far exceeds the cost of protective well testing and treatment through disinfection to return a well to safe water supply.

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Introduction

Owners of individual homes with private domestic wells need a rationale for deciding to disinfect a well suspected of pathogenic microbial contamination possibly resulting in serious illness. An analysis for use in informing well owner decisions about whether to treat a well suspected of being microbially contaminated suggests that protective safety steps cost far less than incurring medical costs and lost wages from illness and possibly death. Many types of microorganisms, including bacteria and viruses, are endemic and evolved to living in saturated sediments and rock. This microflora exists in substantial numbers in aquifers but are generally not harmful to people, that is, causing illness. The occurrence of pathogens—the bacteria, protozoa, and viruses that sicken people—may be sparse and challenging to detect in water.[1] For this reason, public health officials have used common water sample tests for bacteria detection as an early warning mechanism of potentially unsafe water. Total coliforms are indicator microorganisms and are more common and easy to grow and test for in laboratory evaluations, furnishing a margin of safety.[2] Other tests include heterotrophic plate count (HPC) and adenosine triphosphate (ATP) analysis.[3] Pathogens, such as legionella, may occur in groundwater even if coliform bacteria (always existent in the digestive tracts of people and other mammals, but primarily an indicator that surficial soil is in contact with the water) are not present. Detection of *Eschericia coli (E. coli)*, a subset of the coliform bacteria, indicates fecal contamination. Some types of *E. coli,* as well as other fecal bacteria such as giardia, can cause sickness including diarrhea, vomiting and worse effects. The worst type of *E. coli* causes bloody diarrhea, as well as kidney failure and even death.[4]

Using the results of water sample testing, well owners in the United States (and elsewhere) can identify conditions under which microbial contamination may affect the safety of their wells. The well owners can then take accepted cost-effective action to protect their families from unsafe water. These conditions are outlined, the health effects of microbial contamination are specified, and the costs of well treatment are compared to medical response and income effects.

What are the concerns about pathogenic bacteria, virus or protozoa in groundwater?[5 6 7]

Groundwater is generally considered a safe water source[8] in the United States[9], especially from deeper-cased abstraction points.[10] However, flooding or deteriorated well conditions can make groundwater vulnerable to pathogenic bacterial contamination.[11] The Centers for Disease Control and Prevention (CDC) identify the primary causes of microbially-related illness outbreaks from private water systems and wells as: Hepatitis A, Giardia, Campylobacter, E. coli, Shigella, Cryptosporidium, and Salmonella.[12]
Pathogenic microorganisms (including bacteria, viruses, and protozoans) are often associated with animal and human fecal waste generally from a surface source and not usually found in groundwater. Other sources of pathogenic microorganisms include water, soil, and building and home water systems.[13]

Pathogenic microorganisms can cause a variety of diseases including: Salmonellosis, Giardiasis, and Hepatitis A with varied symptoms of nausea, vomiting, diarrhea, fever, headache, and cramps. Salmonellosis sickens more than 1 million people in the United States each year and up to 450 die from Salmonella poisoning annually.[14] Other pathogens causing diarrhea and other health effects and potentially found in wells, particularly after flooding, include *Cryptosporidium* (medication available), *Campylobacter* (affecting about 2 million/year in the US, medication available for severe infection), *Enterovirus* (estimated to cause 10-15 million illnesses/year in the US), *Norovirus* (11 states reported over 1,000 Norovirus outbreaks each year from mid-2017 to mid-2019)[15], *Rotavirus* (vaccine available), and *Shigella.*[16, 17] Typhoid fever is mainly a concern in countries of East and Southeast Asia, Africa, the Caribbean and Central and South America from consuming untreated water and raw vegetables and fruits in those countries. A vaccine is available.[18]

People most susceptible to many pathogens are infants, children, pregnant women, elderly persons and persons with pre-existing illnesses and compromised immune systems. [19]

What factors may lead to microbial contamination of groundwater? [20, 21, 22]

Groundwater in the United States has traditionally been considered the water source least susceptible to contamination by indicator bacteria or human pathogens. This outcome is particularly true of groundwater from deep, better-protected or confined aquifers. If fecal indicator bacteria or pathogens from animal or human feces are present in groundwater, the most likely sources are:

- Nearby connection with a contaminated surface environment, such as seepage from a waste lagoon or contaminated surface water
- Floodwater carrying waste lagoon water or contaminated surface water
- Leaking or improperly operating septic tank
- Broken or leaking sewer line and sewage overflows
- Old or improperly designed landfill
- Runoff from woodlands, pastures, and feedlots; and animals (wild or domestic)
- Backflow from contaminated sources such as a sink-top carbon filter or bucket of water
- Reduced pressure or suction in water lines that draws in soil water at the pipe joints through faulty sanitary seals in the well system when the well cap, grout around the well casing, or pitless adapter connecting an underground water distribution pipe to the well are compromised

What are the uncertainty and risk associated with microbial contamination of groundwater and wells?

If a well has been affected by any factor listed above, a possibility exists that the well may be contaminated, but clearly this is not a certainty. From an uncertainty and risk management standpoint, the probability of some of these sources occurring in any particular situation may be able to be estimated while in other situations the probability cannot be provided. In the latter case, all the specific circumstances of the interacting processes resulting in a contaminating outcome for groundwater or a well may not be fully understood.[23] However, the factors presented above increase the risk of water well contamination and if a well owner suspects contamination, water testing may be an advisable next step to support the safety of well water use.[24]

What is the Test for Pathogen Presence in Water?

Coliforms are bacteria naturally present in the environment with other pathogens and used as an indicator that other, potentially harmful, bacteria, virus and protozoa may be present. Fecal coliform and *E. coli* are bacteria whose presence indicates that water may be contaminated by human or animal wastes and harmful to human health. The presence of these bacteria is tested for in water samples sent to analytical laboratories. In tropical settings and fractured bedrock aquifers, such as limestone commonly found in tropical U.S. territories, total coliform can be ubiquitous, so that further confirmation tests are needed.

In the United States, the cost to test for *E coli* and total coliform in water is $10-$35 per sample,[25, 26] depending on sampling protocol and laboratory. Additional tests could be done for non-fecal derived bacteria and viruses using heterotrophic plate count (laboratory recording of the level of microorganism growth) and adenosine triphosphate analysis (rapid accurate measurement of a universal energy molecule in cells) that might increase the testing cost by approximately $25 per sample for each method.[27, 28]

Are There Recent Examples of Wells Impacted by Pathogens?

Wells may be more vulnerable to pathogenic fecal contamination after flooding, particularly if the wells are shallow, have been dug or augured, drilled in carbonate or sandstone aquifers vulnerable to surface connection, or have been submerged by floodwater for long periods of time.[29] After flooding from hurricanes in 2016 and 2018, the state of North Carolina offered free well water sample testing to people relying on private wells in the state. Typically, about 2 percent of private wells in North Carolina test positive for *E coli* and total coliform bacteria.[30]

The state laboratory received well water samples from 18 counties in eastern North Carolina after Hurricane Matthew in 2016, and about 27% of the well samples tested positive for *E coli* and/or total coliform.[31] Thirty-two (32) wells were sampled two to four times to check that the wells were safe for use. Additionally, 24 wells tested positive for coliform or *E. coli* but did not have samples submitted for retesting, potentially presenting a health risk to the well users.[32] After Hurricanes Florence and Michael struck North Carolina 28 days apart in 2018, the state again offered free water sample testing to owners of private wells in 25 counties with 997 well water samples submitted for testing. As of January 2019, the state laboratory found 45 percent of samples tested positive for *E coli* and/or total coliform bacteria.[33] Similarly, flooding in North Carolina and neighboring states from Hurricane Floyd in 1999 resulted in 12,000 wells being affected with over 15 percent testing positive for total coliform. [34]

Thus, in both the 2016 and 2018 flooding of counties in North Carolina, the state laboratory documented a significant increase in the number of private wells affected by fecal contamination apparently as a result of flooded wells and/or high water tables that hydrologically connected septic systems or other sources of fecal contamination to wells.[35] The National Ground Water Association estimated that nearly 667,000 households on private wells in six states may have been affected by the 2018 Atlantic hurricane season and more than 1 million households on wells were in 300 Midwestern counties of ten states flooded by late 2019 winter storms.[36] The specific number of wells affected was not able to be determined.

What is the Human Impact of Pathogenic Bacteria, Virus and Protozoa in Water?

While most illness from microbial pathogens in the United States is not from water consumption, some waterborne illness does occur. The extent to which a person may be exposed may not be able to be known prior to the exposure and the observation of the health effects on the individual. The probability of adverse effects to an individual in any particular incident of pathogen infection may not then be able to be estimated. The Centers for Disease Control and Prevention (CDC) estimates Salmonella causes about 1.2 million illnesses, 23,000 hospitalizations, and 450 deaths in the United States every year. Among these illnesses, about 17 percent are not food related.[37] Illness from salmonella infection typically last from 3-7 days without treatment and usually include diarrhea, abdominal cramps and fever of 100 to 102 degrees F.

Of the different kinds of *Escherichia coli (E. coli),* most are harmless, but some can be harmful and are usually transmitted through contaminated food or water. Outbreaks usually evolve from exposure to the harmful shiga toxin-producing E. coli (STEC) causing stomach cramps, fever, diarrhea and vomiting. Mild infections may pass in 5-7 days. In children and in people who are elderly or of compromised condition, kidney failure can occur and require dialysis. Although larger outbreaks of *E. coli* receive more attention, "*E. coli* infections are not uncommon" and may result in hospitalization and in some cases death.[38]

In the 40 years prior to 2001, 4,600 people were hospitalized with giardiasis annually in the United States.[39] *Giardia Lamblia* cysts have been found in cisterns and in hand-dug wells contaminated by surface water or sewage. Concentrations are often elevated in water sources associated with agriculture (e.g., cattle or dairy farming) or municipal and residential wastewater discharges. Contamination levels may vary because of storms, agricultural activities, and proximity to wastewater facilities. Giardiasis is the intestinal protozoan infection recorded most frequently around the world with 200 million people estimated to be infected each year. Death from Giardia infection is infrequent. Children under five years old are the main group hospitalized primarily from dehydration.[40]

"Hepatitis A is a viral liver disease that can cause mild to severe illness. The hepatitis A virus (HAV) is transmitted through ingestion of contaminated food and water or through direct contact with an infectious person. Almost everyone recovers fully from hepatitis A with a lifelong immunity. However, a very small proportion of people infected with hepatitis A could die from fulminant hepatitis. The risk of hepatitis A infection is associated with a lack of safe water, and poor sanitation and hygiene (such as dirty hands). Epidemics can be explosive and cause substantial economic loss." `[41] Hepatitis E virus (HEV) is mostly transmitted through consumption of contaminated water or food. HEV is a common cause of hepatitis outbreaks in developing parts of the world and is increasingly recognized as an important cause of disease in developed countries.[42, 43]

Typhoid fever is from a serotype of Salmonella and may serve as an example of documented effects of infection from microbial pathogens. According to Centers of Disease Control (CDC), about 300 cases of typhoid are diagnosed in the United States each year. Seventy-nine (79)% of the cases were foreign-travel related.[44] Two different studies reported separately in 2011[45] and 2017 [46] found that 81% of people diagnosed with microbial infection received out-patient treatment with adults' illness lasting 12-21 days and losing 18 days of work. More serious cases resulting in-patient care had 27 lost work days from illness and treatment and hospitalization of 4.2 days. It is also estimated that 2.9 million cases of cholera derived from fecal contamination of water continue to occur worldwide every year with an estimated annual mortality of 95,000.[47]

In sum, in worst cases of these and other waterborne disease potentially caused by fecal-contaminated or enteric virus-contaminated water entering wells from floods, high water tables hydrologically connecting septic systems to wells or other events, illness can be extended and, if severe, can result in hospitalization and in extreme instances end in death.

What is the Cost of Waterborne Microbial Illness?

The US Department of Agriculture Economic Research Service (ERS) in 2010 for the United States estimated that Salmonella infections from all sources and resulting in medical treatment cost an average of $1,896 based on 1.4 million cases annually with 415 deaths. ERS also estimated that *E coli* O157 cases that were treated medically had an average cost per case of $6,510 based on 73,480 cases each year from all sources and including 61 deaths. The USDA cost estimates include medical costs, time lost from work due to nonfatal illness, and the cost of premature death. They exclude several other potential costs, such as pain and suffering, travel, and child care, as well as costs to government. These costs do not include possible costs of physical distress, transit, and family services nor the long-term costs of persistent problems from Salmonella and training and convalescent needs of *E coli*-infected patients. The US Department of Agriculture Economic Research Service uses CDC estimates of food- and waterborne disease in cost-benefit and impact analyses.[48]

"The Centers for Disease Control and Prevention (CDC) has estimated [for 2003] that Shiga toxin-producing *Escherichia coli* O157 (0157 STEC) infections cause 73,000 illnesses annually in the United States, resulting in more than 2,000 hospitalizations and 60 deaths. … The annual cost of illness due to O157 STEC was $405 million (in 2003 dollars), including $370 million for premature deaths, $30 million for medical care, and $5 million in lost productivity. The average cost per case varied greatly by severity of illness, ranging from $26 for an individual who did not obtain medical care to $6.2 million for a patient who died from hemolytic uremic syndrome." [49]

Specific minimum costs for a severe reaction to waterborne illness involving hospitalization may include:

- One-month duration of illness with 20 days of lost wages at $175 per day (the average wage in the United States in 2017 was $44,564 per year [50] or $45,455 in 2018$US ($21.85 per hour)) = $3,500.
- At least two visits to a physician's office for diagnosis and treatment estimated at $150 per visit [51] = $300

- At least one test for pathogens in blood estimated at $100 per specimen[52] = $100
- Prescription medication,[53] low cost = $10; high cost = $790
- A typical in-patient stay in a hospital in the United States in 2018 is about 5 days that may cost over $10,000, or over $2,000 per day. This figure does not include major procedures, ambulance fees, or other charges[54, 55] = $8,000 for 4-day hospital stay

In the case of a person having a severe waterborne pathogen infection lasting one month with loss of pay for 20 days away from work and requiring a hospitalization of at least 4 days, the cost to an individual would be $11,910 to $12,690. This estimate should be considered a minimum amount in the case of a severe infection not resulting in death. If multiple residences are sharing a well and all people are exposed, the potential health-and-medical-related cost impact could be two to twenty times (or more) this amount. For example, if four homes draw on a shared well that is infected and each home has two wage earners who become severely ill, the cost could be eight times $11,910, or $95,280 on the low end and range up to $101,520 on the high end. The customers of a small public water system serving 40 people with 20 wage earners with serious infection could incur costs of $238,000 to $254,000.

What is the Cost of Treatment for A Private Domestic Water Well?

Routine inspection of a private domestic well involves examining the wellhead and the area around the well to determine that proper operation and conditions exist for safe groundwater supply: check for damage to well casing and apron; check for correct distances from structures, wastewater treatment, and sources of potential microbial and chemical contamination and their removal; proper ventilation of equipment; sound electrical connections; and adequate elevation to reduce floodwater effects. Costs for inspection of a private domestic water well conducted by a qualified water well professional range from $80-$325 depending on the location and conditions of the well.[56, 57] Ideally, well inspections would be done annually and before a potential contaminating event occurred to avoid or minimize the possibility of having unsafe well water.

Well disinfection using chlorine involves well cleaning[58] and then chlorination, the most effective means to destroy pathogens in wells and plumbing.[59] Notably for wells impacted by floodwaters, typical preventive disinfection may not be adequate to inactivate pathogens in affected well water because of the higher loads of contaminants and sediment carried by floodwater that may enter the subsurface[60] as well as growth of biofilms on well casing and screen that can support bacteria.[61] A qualified water well professional will at least perform: determining age, diameter, depth and materials used in constructing the well for proper cleaning and disinfection; calculating amount of chlorine and pH adjustment based on well construction; introducing chlorine disinfectant to the well; managing chlorine distribution and contact duration in the well and residential/building plumbing; resampling well water and sample submission to a testing laboratory; confirmation resampling over 3 months and then annually. Most effective well disinfection is accomplished when the pump is removed from the well.[62] Well disinfection/chlorination performed by a qualified water well professional may cost as much as $500 to $1,000 depending on the size and depth of the well and other well characteristics.[63, 64]

What Can Cost-Benefit Analysis of Disinfecting Wells Testing Positive for Pathogens Show?

A cost-benefit analysis compares the costs of an action or activity to benefits related to that action or activity. To conduct a cost-benefit analysis of disinfecting wells at the individual domestic well owner level, costs leading up to and including well disinfection are compared with the avoided cost of drinking contaminated water and suffering illness and possibly mortality. While the probability that an individual well may or may not be contaminated from a particular incident addressed in "What factors may lead to microbial contamination of ground water?" above, a well owner may desire to consider the costs of well disinfection as a protective action in comparison to the avoided-cost benefits of not having a waterborne illness from consuming potentially microbially-contaminated groundwater. The cost figures used below are taken from the literature cited above; therefore, the costs could be lower or higher depending on circumstances.

Prevention Costs per Domestic Well for Water Safety to Avoid Illness and Possible Death:

- Cost of well inspection to avoid major well reliability and contamination problems = $80-325, depending on well location and conditions
- Cost of well water sample testing = $35 (potentially more if other more comprehensive testing is done ($25 each for HPC and ATP analyses))
- Cost of well disinfection to clean well of bacteria, virus and protozoa = $500-$1,000
- Cost of followup well water sample verification test = $35
- A well owner suspecting microbial contamination of a well could go directly to water sample testing, disinfection if the test is positive, and followup testing, spending $570. Annual well inspection, which also could include water sample testing, is recommended.

  Some states have offered free well water sample testing when extreme hurricane storm flooding has occurred, potentially having affected 1,665,000 households with wells in the southeastern and midwestern United States [65, 66]

Avoided-Cost Benefits per Individual Well Owner for Taking Health Protective Action

For an individual with a severe waterborne disease infection of one month, two doctor's office visits, one blood test, prescription medication, an average hospitalization of 4 days, and lost wages for 20 work days, the cost would be $11,910 to $12,690.

Setting aside the cost of premature death, the avoided-cost savings (benefit) is estimated to be $11,910-$12,690 for medical treatment and lost wages compared to the well safety cost range of $570 to $1,395.

If multiple residences share a well that becomes infected, the disinfection cost to each residential owner goes down while the benefit of avoided medical expenses and wage losses increases proportionately with each individual potentially affected. For example, if four homes with two wage earners each are affected, the cost of inspection and disinfection would be $570 to $1,395 compared to the potential medical and lost wages costs of $238,000 to $254,000. In this example of a shared well, the cost of disinfection and testing per residence decreases to a range of $143 to $349.

Including the cost of premature death avoided increases the benefits for a potentially affected individual by approximately 100 times, a very significant result.

Other Benefits from Well Inspection and Disinfection

Well owners can receive other benefits from well inspection and disinfection to guide future decisions. The advantages include gathering information about age, condition, material and construction of the well and pump, as well as knowledge about structures, vegetation and location of potential contaminants that could interfere with the well and affect its water source and needs for any other attention to ensure continued use of the well. This information could provide well owners the ability to maintain groundwater supply through their own management steps and control.

Conclusions

Well owners making decisions to respond promptly to suspected microbial contamination of a well is health protective and cost-effective. Ideally, decisions to keep well water safe would be made through annual preventive well inspections to avert or minimize water contamination rather than reacting to contaminating events. Sample testing is not expensive for E. coli and total coliform, the indicator organisms for fecal microbial contamination, nor for other microbial testing. The human cost of medical treatment and lost income far exceeds the cost of protective well testing and treatment through disinfection to return a well to safe water supply. Information from well inspection and disinfection provide well owners future advantages for independent control of their groundwater supply.

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