Is Groundwater a Threat to Biosecurity?

By
Grant Olsen

Forward

Misconceptions about what causes a disease and how it spreads have been very numerous throughout history that have at times, been so engrained in the scientific community that to think outside of the box was branded as ludicrous. In 2005 the Nobel Prize in medicine went to a man named Barry Marshal for his discovery that ulcers were not caused by stress or eating habits, but by bacteria. When he initially announced this discovery during the early 1980's, the brightest minds in medicine rejected it as it went against the conventional thinking, which the medical industry had embraced for decades. Wherein, stress and diet had been known to be the primary causal agents. However, after a period of nearly 25 years after Marshal's discovery, scientific research won out and the truth was accepted.

In a more related anecdote the discovery of water as a vehicle for disease transmission was thought preposterous by a large part of the medical community for the same reason. During the part of the 19th century, when this discovery was made, the prevailing idea behind disease transmission was the miasma theory. Miasma or "bad air" was thought to cause disease in areas that contained a bad stench or aura of sickness. John Snow was skeptical of this and when a cholera outbreak stuck the heart of London in 1854 he got the chance to investigate. In his study, he was able to link cholera outbreaks to contaminated water. This culminated in the public well responsible for the outbreak being shut down, and the incidence of disease soon following suit.

Today we face a somewhat similar oversight with our faith in the biosecurity of groundwater.

What We Know Today

Based upon numerous empirical studies, groundwater is in fact a significant vector for transmission of disease. This realization prompted the introduction of the Ground Water Rule (GWR) as part of the *Safe Drinking Water Act (SDWA). The GWR was adopted in 2006 with measures to ensure the microbiological safety of public drinking water due to the threat of groundwater presented to bio-security of human populations. However, the risk to biosecurity on farms caused by groundwater, to date has largely been ignored. This suggests a significant disparity in terms of knowledge, risk assessment, and remedial strategies in address of biosecurity of water in use for general human consumption and that being used within the animal production industry.

** Please note, the SDWA excludes Private and Agricultural water supplies.*

The risk presented by viral illness to the agricultural industry is especially of note due to outbreaks of viral illnesses that have continued over a period measured in decades. This is of special concern given the statistic that viral illness are four times more likely to be the source of illness in ground water then in surface water (Gerba 2004). To date it is known that up to 50% of wells are positive for enteric viruses (Borchardt , Haas, Hunt). While, a number of water conditioning products have been marketed under the guise of water treatment and/or disinfection by unknowledgeable veterinary supply and water conditioning companies, none have represented technologies and/or application methodologies that otherwise must be compliant with performance certification or adherence to engineering design standards as would otherwise be required within the public drinking water industry.

In effect, nearly 100% of the water disinfection systems currently in use today within the agricultural industry <u>will not inactivate virus or any other pathogen to known level (Log_{10} Inactivation Rating), if at all</u>. For instance: A.) The use of a chemical metering pump to inject a "disinfectant" directly into a water pipe as a means to eradicate pathogens from a source water supply would be considered ridiculous and laughable within the public water treatment industry. B.) Chlorine Dioxide, which has been marketed heavily over the past 15 years within the ag industry within a container with a label which notes the solution it contains is 5% aqueous Chlorine Dioxide is false. What it actually contains is Sodium Chlorite. Which in terms its use for disinfection of water, is very limited. Wherein, when reagent concentrations (such as 5% Sodium Chlorite) are mixed with similar concentrations of Acid, and/or an Oxidant, within a mixing chamber (in the absence of water) that Chlorine Dioxide can be generated at a sufficient concentration to be injected into a water supply to cause a meaningful level of disinfection of microbial pathogens. C.) In the event the company marketing "Bottled Chlorine Dioxide" also provides a test strip to verify its concentration with a treated (thus Disinfected) water stream, it is suggested that you purchase a *Chlorine Dioxide test kit that is compliant with an ASTM and/or EPA analytical test standard. Then compare the results between the test strip and the test kit in regards to the differing measurements of concentration. D.) While many other examples can be identified, including them within this paper would require the addition of numerous pages to this paper and distract from the primary aim of the intended subject matter.

* (https://www.hach.com/chlorine-dioxide-color-disc-test-kit-model-cld-2/product?id=7640219527)

Viable and treatment methods remain absent within the agricultural industry that would otherwise ensure inactivation pathogens within livestock drinking water. This has left a significant vehicle for disease transmission unaddressed and underestimated.

Impurity of Groundwater

The presence of viruses in groundwater should be no surprise as it has been known for some time that ground water is not safe from microbial agents. Not only was this addressed by the GWR in 2006 but had been on the radar of academia with studies indicating viruses in groundwater dating back to the 1980's (Yates et al, 1985). Of specific interest to the animal health industry may be the AWWA study entitled *Occurrence of Viruses in US Groundwaters* (Abbaszadegan et al. 2003) that included the results of a random study of 448 groundwater wells that were serving as the source water for public water systems (Cities) throughout the US. This study suggests that 31.5% of cities within the US that use a groundwater source for their public drinking water supply may be subject to viral contamination. In addition, 15.1% tested positive for bacteria. A more recent study of interest, conducted by the Minnesota Department of Health in 2015 that included a random study of 82 municipal wells, suggested an occurrence rate of 36+% for enteric viruses. A conjecture against this that has often been raised is that, most of these studies looked at human viruses and not swine, of particular note here is Porcine epidemic diarrhea virus (PEDv). However studies of the survivability of virus' in the same subfamily as PEDv (Coronavirinae) indicate the time taken for the virus to lose infectivity can last over 100 days in groundwater, a time period that has been shown to get longer in colder conditions (Gundy, Gerba, Pepper; 2008). Thusly, the implications to animal health posed by contaminated ground water cannot be over looked.

The logic behind groundwater as being a safe drinking water source has been based in our past understanding that groundwater aquifers are protected from chemical and microbiological contamination by overlaying soil and sediment layers. In effect, water from precipitation recharging aquifers needs to pass these zones, which act as effective mechanical and biological filters, hence providing a natural clean up of newly generated groundwater (Herman et al. 2001). Further, it was generally understood that pathogens would not survive over the long duration of time required for surface water to migrate into groundwater aquifers. Nevertheless, today the manner in which groundwater aquifers are recharged is better understood and the presence of pathogenic agents, generally classified as Virus, Bacteria, and Protozoa, are commonly found within groundwater aquifers. This understanding has enabled us to make the following observations;

1. Aquifers do contain contaminants of both chemical and biological origin.

2. Natural hydraulic pathways (such as fissures, caves, and veins of sand, gravel, and unconsolidated rock formations) through which contaminated surface water from precipitation, lakes, marshes, and rivers may enter aquifers rapidly and with minimal filtration, either characterize their entry to aquifers. (Krauss and Griebler, 2011)

3. Viral pathogens exist and can remain infectious (viable) within ground water aquifers from weeks to years based upon groundwater temperature, and content of organics and solids. Of the physical factors influencing virus survival in a liquid media, temperature, sunlight, and virus association with solids are among the most important factors influencing survival (Sobsey, et al. 1993) (Figure 1). Likewise, viral pathogens that penetrate though soils into groundwater aquifers can remain viable for an extended period of time

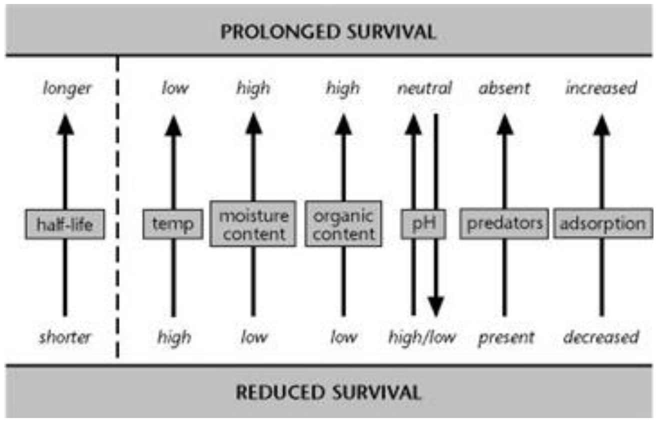

Figure 1: Factors affecting virus survival and half-life (from Coombs et al 2000)

4. The penetration of pathogenic viruses through soils and geological strata into aquifers seems much more likely than for pathogenic bacteria and protozoa (Schijven and Hassanizadeh 2000), due to their size relative to the interstitial (void) space(s) between the physical granules of what soils and unconsolidated sedimentary layers they may pass through (Figure 2).

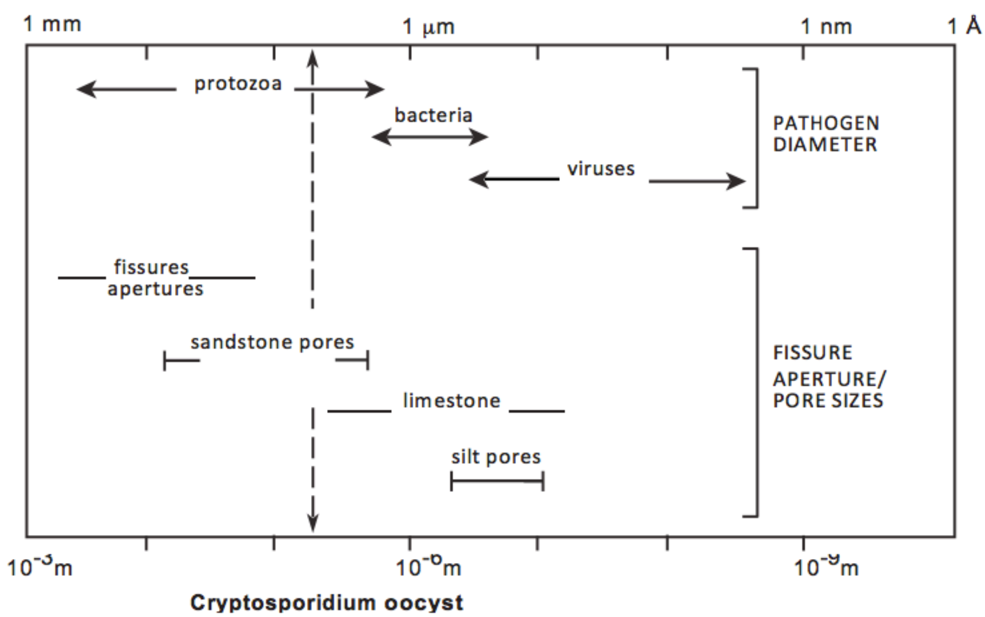

Figure 2: Pathogen diameters compared to aquifer matrix apertures (Morris, et. al.)

5. Viral pathogens have much longer survival times in water than most intestinal bacteria; they are generally more infectious than bacteria and protozoa and are remarkably resistant to common disinfection treatments (Fong and Lipp 2005).

6. The risk of viral contamination of water increases further because of the extremely high numbers by which enteric viruses are shed into the environment. For instance PEDv is found at concentrations of 1.1 x 10^5 (110,000) copies/mL in earthen manure storages. (Tun et.al Front Microbial. 2016; 7: 265.) In effect, one liter of manure may contain up to 110,000,000 PEDv's.

7. Water within an aquifer may travel extreme distances, and at various speeds & direction. Likewise, the following is understood and accepted:

    a. Contaminants that enter an aquifer at one geographic location may travel and remain viable for many miles in advance of being detected within a well that is located within an area that is presumably absent of the risk of microbial contamination based upon localized geological structure and surrounding geography.

    b. Such migratory plumes of contamination can be of any size, travel at various speeds, and direction. What this means is water entering a well system may contain pathogens that have either been within an aquifer for a few hours – days – months -to many years. (Figure 3)

    c. It is also known that microbes may appear/disappear (MDH Study 2015) within any given well system within a matter of day(s). *In other words*, if a livestock operation wishes to prevent waterborne pathogens from entering a bio-secure farm, the water would need to be tested to verify the absence of biologicals on a continuous basis with an analytical method capable of providing results on a real-time basis. As this is impractical, a more logical, and cost-effective approach would include the ongoing deployment of disinfection technologies. Similar to what Municipalities currently use to provide ongoing biosecurity of treated drinking water supplies.

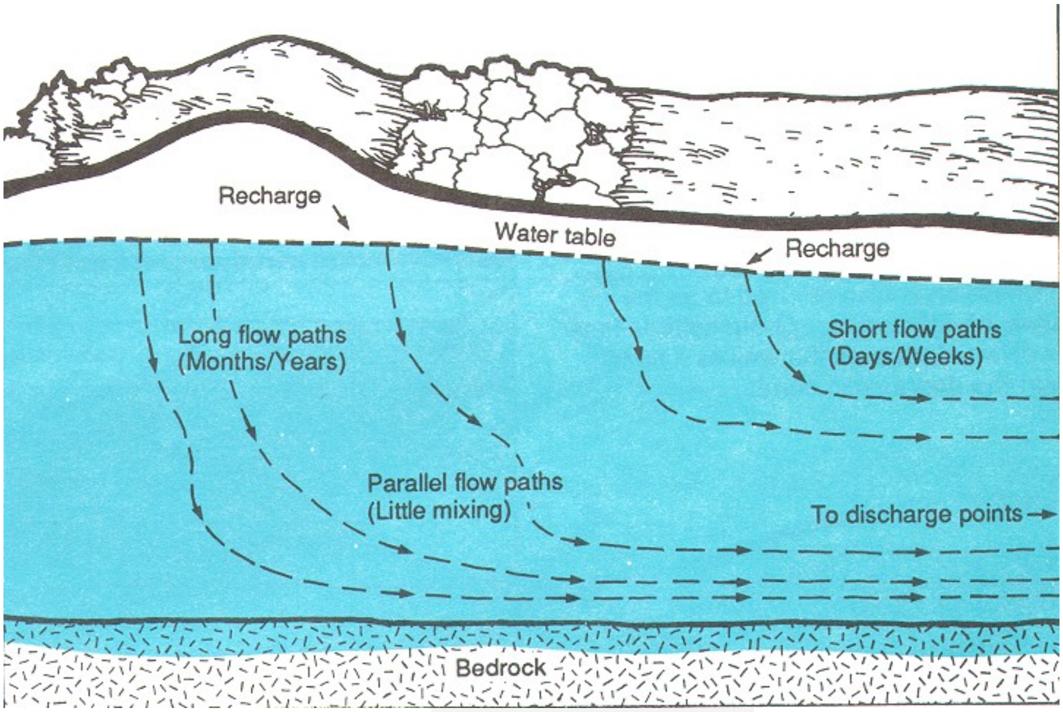

Figure 3: Groundwater Flow Paths
Center for Science & Environmental Education
Michigan Technological University

Aquifer Discharge

Figure 4: Discharge of the Eastern Snake River Plain aquifer from basalt cliffs above the Snake River gorge, Idaho, USA. The water flows from fissures along the same horizon. Faults, fractures, and rock layers strongly influence the flow paths of groundwater. (USGS)

8. Due to growing populations and expanding land use, sources of pathogen-contaminated wastes steadily increase hence, also raising the potential pollution of groundwater aquifers with infectious agents. (Figure 4) This is mainly true for pathogens originating from human and animal feces. Sources of fecal contamination in groundwater potentially include the following:

    a. Leakage from on-site sanitation systems such as septic tanks or sewers,
    b. Underground storage tanks,
    c. Disposal systems,
    d. Animal manure and compost,
    e. From (accidental and non-accidental) wastewater discharge
    f. Sewage sludge applied to fields in agricultural areas. (Reynolds and Barrett 2003; Gerba and Smith 2005; Arnone and Walling 2007)
    g. Surface waters receiving treated or untreated sewage from human sources or livestock enterprises and discharge from non-point sources like urban and agricultural runoff are a steady source and reservoir of pathogenic agents (Kirschner et al. 2009)
    h. Naturally occurring points of infusion of surface water in aquifers via water catchments, stream banks, and lake beds.

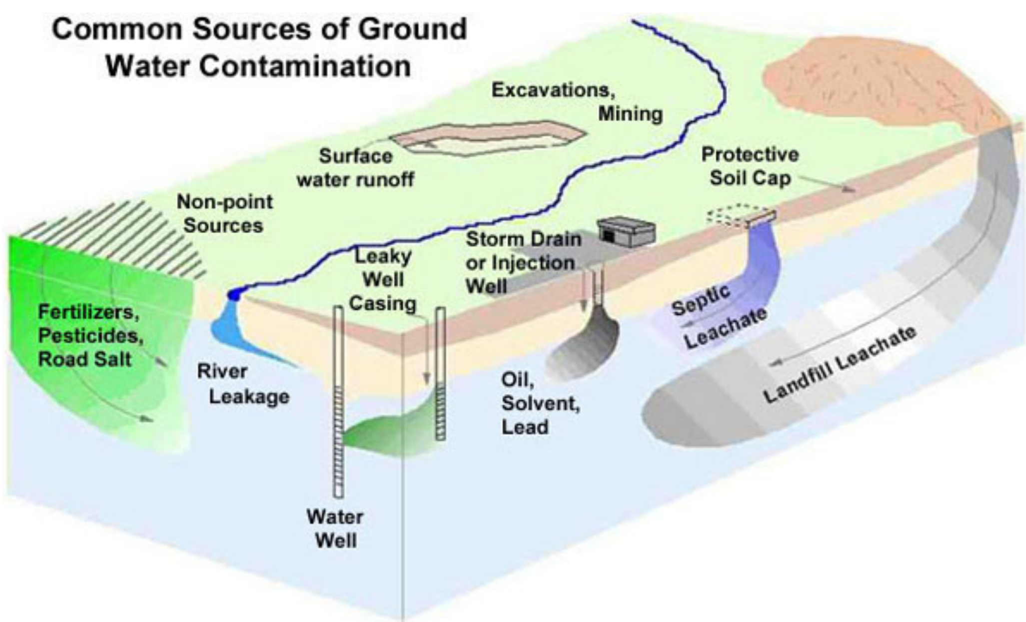

Figure 5: Common sources of groundwater contamination

9. Further, a serious source of pathogens entering soils and groundwater is diffuse contamination (non-point sources), for example from spreading of manure to fields and crops. Similar to human feces, animal manure may contain high concentrations of pathogenic organisms including bacteria, viruses, protozoa and helminthes, potentially

> causing zoonotic diseases in humans (Cotruvo et al. 2004; Gerba and Smith 2005). This poses a risk for human health in rural areas (Bianchi and Harter 2002; Cotruvo et al. 2004), arising for example from frequent contamination of private wells that are used for the drinking water supply of farms. A statistical evaluation of 1,200 rural farms in the US revealed that approximately one-third of the wells were, from a hygienic and bacteriological point of view, contaminated (Goss and Barry 1995).

Given this data, it is quite improbable that untreated or improperly treated groundwater has not represented a risk factor for disease outbreaks. The ability of pathogens, especially virus to reach the groundwater via natural geological pathways, now liberates ones understanding to include a very significant pathway, the now may represent "the smoking gun" as to why many infectious diseases have been resilient to preventative measures and likewise continued to be so persistent within the livestock industry over a period measured in decades. In effect, one of the primary vectors for their transmission has, and remains unhindered.

PED compared to other known waterborne virus.

Two very widely known waterborne viruses are norovirus and rotavirus, two of the pathogens in the aforementioned study that was associated with a statistical significance of over 99.99%. (Gallay et al, 2006) Of an interesting note, norovirus shows clinical signs of gastroenteritis (diarrhea and vomiting), similar to the presentation of PEDv in swine. Further this virus is also sloughed off in feces and is thought to transmit through the fecal oral route. All characteristics shared with PEDv. This virus has been known to cause epidemic out breaks of disease in populations especially in colder months due to its increased viability in colder ground water. (Greer et al, 2010) This trend is of seasonality is also demonstrated within the swine population in regards to outbreaks of PEDv. This reflects the ability of the virus to stay infectious in cold water for a longer period vs. when in warmer water.

The need to address biosecurity via groundwater becomes even more evident when the body of evidence has been examined for the transmission of PEDv. A prevalent belief is PEDv is mainly transferred via an airborne route, which is in part due to how quickly it spreads and reports linking its transfer to wind directionality. However studies that have been done to prove the virus can travel air borne have shown that only the genetic material of the disease (RNA) can travel for up to 10km. *(Alonso et al)* In that same study when the infectibility was assessed it was shown the <u>airborne particles collected in the field where unable to infect pigs.</u>

> *"Bioassay completed with air samples collected under experimental conditions demonstrated that PEDV could remain infectious while airborne. <u>However, inoculation with samples collected under field conditions did not result in PEDV infection</u>. The lack of infectivity could be attributed to the lower viral concentration in the field samples or*

the inactivation of the virus by temperature, solar light intensity, ultraviolet radiation…" (Alonso et al)

This is to say that virus particles in the field can be deactivated by sunlight, temperature changes and UV irradiation severally limits the Airborne Vector as a viable route for transmission.

Solutions

Based upon the progressive actions employed over the past decade within the livestock production and health industry related to biosecurity in the areas of transportation, air quality, modality, and feed supplies, it becomes apparent there is one area is has not been addressed. This area is recognized globally as one of the most significant for the transmission of infectious disease. It is also considered the most important livestock nutrient. This is drinking water. Wherein, to ensure water that enters a facility is free of pathogens and then remains free of pathogens throughout each facilities drinking water distribution system(s), viable measures of biosecurity must be employed. <u>Within the public drinking water industry, these two areas of biosecurity are referred to respectively as Primary and Secondary Disinfection.</u>

<u>Primary Disinfection (Definition):</u>
The treatment process element where a chemical and/or non-chemical disinfection process is used to achieve defined level of microbial inactivation and/or removal of pathogenic microorganisms from a given source water supply that satisfies the USEPA's drinking water quality standards.

<u>Secondary Disinfection (Definition)</u>
There are a few pathogenic and potentially pathogenic bacteria that naturally occur in aquatic environments. Infecting their host they take opportunity of weakened defense mechanisms and hence are called an opportunistic microorganism. They typically inhabit surface waters <u>or appear to grow in biofilms in water pipes causing regular problems in drinking water distribution systems</u>. (Krauss et al. 2011)

Likewise, **secondary disinfection** includes the application of a chemical disinfectant at the beginning, and at appropriate points along the water distribution network, to maintain a targeted residual throughout the system as a preventative measure from reverse contamination through water fixtures and for the eradication and prevention of biofilms within the water distribution system itself.

Discussion

The commonly held belief that groundwater is microbiologically safe and is not a concerning vehicle for disease transmission is not only untrue but also detrimental. It is important to address this vehicle for disease transmission in the agricultural industry in order to obtain the best possible levels of biosecurity. This area has already been addressed with the GWR for human consumption and should a similar response from the agricultural in dusty. It is possible to negate the risks caused by groundwater via steps of proper primary and secondary disinfection. These steps should be taken whenever using groundwater as well as increased study into the role of groundwater in disease transmission as it relates to the agricultural industry.

References:

1. Abbaszadegan, Morteza, Gerba Charles, and Mark W Lechevallier. "Occurrence of Viruses in Us Groundwaters." American Water Works Association 95 (2003): 107-09.

2. Alonso, Carmen, et al. "Evidence of Infectivity of Airborne Porcine Epidemic Diarrhea Virus and Detection of Airborne Viral Rna at Long Distances from Infected Herds." Veterinary Research 45.1 (2014): 73.

3. Bianchi, M., and Harter, T. (2002): Nonpoint Sources of Pollution in Irrigated Agriculture. ANR Publication 8055 FWQP REFERENCE SHEET 9.1: 1-8

4. Borchardt, Mark A., Nathaniel L. Haas, and Randall J. Hunt. "Vulnerability of Drinking-Water Wells in La Crosse, Wisconsin, to Enteric-Virus Contamination from Surface Water Contributions." (2004).

5. COOMBS P, MORRIS B L AND WEST J M 2000. Transport and fate of Cryptosporidium and other pathogens in groundwater systems UKWIR publication 00/DW/06/11, UKWIR London

6. Cotruvo, J.A., Dufour, A., Rees, G., Bartram, J., Carr, R., Cliver, D.O. et al. (2004): Waterborne Zoonoses - Identification, Causes, and Control. World Health Organization (WHO) 2004. IWA publishing

7. Fong, T.T., and Lipp, E.K. (2005): Enteric viruses of humans and animals in aquatic environments: health risks, detection, and potential water quality assessment tools. Microbiol Mol Biol Rev 69: 357-371.

8. Gallay, A., et al. "A Large Multi-Pathogen Waterborne Community Outbreak Linked to Faecal Contamination of a Groundwater System, France, 2000." Clin Microbiol Infect 12.6 (2006): 561-70.

9. Gerba, C.P., and Smith, J.E., Jr. (2005): Sources of pathogenic microorganisms and their fate during land application of wastes. J Environ Qual 34: 42-48

10. Gerba, Chales. "Why the Concern About Pathogens in the Water.": southwest hydrology, 2004. 14-27. Vol. November/December. .

11. Goss, M., and Barry, D. (1995): Groundwater quality: Responsible agriculture and public perceptions. Journal of Agricultural and Environmental Ethics 8: 52-64.

12. Greer, A. L., S. J. Drews, and D. N. Fisman. "Why "Winter" Vomiting Disease? Seasonality, Hydrology, and Norovirus Epidemiology in Toronto, Canada." Ecohealth 6.2 (2009): 192-9.

13. Gundy, Patricia M., Charles P Gerba, and Ian L. Pepper. "Survival of Coronaviruses in Water and Wastewater." undefined (2018).

14. Herman, P.M.J., Middelburg, J.J., and Heip, C.H.R. (2001): Benthic community structure and sediment processes on an intertidal flat: results from the ECOFLAT project. Continental Shelf Research 21: 2055-2071.

15. Kirschner, A.K., Kavka, G.G., Velimirov, B., Mach, R.L., Sommer, R., and Farnleitner, A.H. (2009): Microbiological water quality along the Danube River: integrating data from two whole-river surveys and a transnational monitoring network. Water Res 43: 3673-3684

16. Krauss, S., Griebler, C. (2011): Pathogenic Microorganisms and Viruses in Groundwater, Project: Georessource Wasser – Herausforderung Globaler Wandel, Helmholtz Zentrum München, Institut für Grundwasserökologie

17. Minnesota Department of Health. "Virus in Minnesota Groundwater." http://mowa-mn.com/wp-content/uploads/2017/03/Viruses-in-Minnesota-Groundwater.pdf.

18. Morris, Brian. "Pathogens and Groundwater."

19. Patricia M. Gundy, Charles P. GerbaIan L. Pepper. "Survival of Coronaviruses in Water and Wastewater | Springerlink." (2018).

20. Reynolds, J.H., and Barrett, M.H. (2003): A review of the effects of sewer leakage on groundwater quality. Water and Environment Journal 17: 34-39

21. Schijven, J.F., and Hassanizadeh, S.M. (2000): Removal of Viruses by Soil Passage: Overview of Modeling, Processes, and Parameters. Critical Reviews in Environmental Science and Technology 30: 49 - 127

22. Sobsey, M., and Meschke, J. (1993): VIRUS SURVIVAL IN THE ENVIRONMENT WITH SPECIAL ATTENTION TO SURVIVAL IN SEWAGE DROPLETS AND OTHER ENVIRONMENTAL MEDIA OF FECAL OR RESPIRATORY ORIGIN, World Health Organization (WHO)

23. Tun et.al (2016) Monitoring Survivability and Infectivity of Porcine Epidemic Diarrhea Virus (PEDv) in the Infected On-Farm Earthen Manure Storages (EMS). Front Microbiol 7: 265

24. Yates, M. V., C. P. Gerba, and L. M. Kelley. "Virus Persistence in Groundwater." Appl Environ Microbiol 49.4 (1985): 778-81.