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An Alberta Perspective on the Migration of Surface Water Pathogens to Groundwater Aquifers: A Literature Review and Brief Analysis

By

Tristan Goodman, Ph.D.

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Alberta Energy and Utilities Board, Environment Group

The following is an overview of the issues and conclusions found in the peer-reviewed literature on the migration of surface water pathogens to groundwater aquifers. Surface and groundwater is part of the hydrologic cycle and are directly connected to one another. However, this does not necessarily result in a conclusion that pathogens in surface water will enter groundwater aquifers or are dangerous to human or aquatic users if entry to groundwater sources does occurs. In the case of this study, focus looks specifically at the potential for pathogen contamination of groundwater from drilling fluid used in the oil and gas industry in Alberta. These drilling fluids use untreated surface water. Concern has been expressed over the use of untreated water being used in drilling fluids and its potential to contaminate groundwater sources.

Pathogens include protozoa, bacteria, and viruses.

> **Protozoa** -- This group includes Giardia and Cryptosporidium, two of the most well-known microorganisms. Protozoa are relatively large by microorganism standards (1-16 microns. 1 micron = 1 millionth of a meter). This makes them relatively easy to filter out of water. Protozoa are more resistant to changes in chemical environments than bacteria or viruses.[i]
>
> **Bacteria** -- This category includes microorganisms like E. coli, Salmonella, Cholera and others. Bacteria tend to be smaller than Protozoa (from .2 to 9 microns). Bacteria are not resilient when transferred to a different chemical environment. They may not be filtered through natural groundwater aquifers (will depend on type of pathogen and geology).[ii]
>
> **Viruses** -- Commonly known viruses include Rotavirus and Hepatitis A. Viruses are extremely small (.02 to .085 microns) which makes them less susceptible to being trapped in a filtration process (rarely get filtered out). Similar to bacteria and different to protozoa, viruses are not resilient when placed in a different chemical environment.[iii]

Five factors that effect pathogen migration from surface water to groundwater (and within groundwater) are:

1. Pathogen life expectancy,
2. hydrostatic pressure,[iv]
3. temperature,[v]
4. biochemical environment (pH, reaction with soil, nutrient levels, redox condition, etc.),[vi] and

5. size of pathogen versus filtration constituents.[vii]
6. length of flow path in the aquifer.

Conclusions From Literature

The peer-reviewed literature reaches a conclusion that it is theoretically possible for an injected pathogen to contaminate a groundwater aquifer. Literature also shows that this is directly dependent on the type of pathogen, life expectancy, temperature, nutrient levels in the aquifer, hydrostatic pressure, hydrogeological setting and number of pathogens injected. No literature was located that specifically examined the oil and gas industry in Alberta. Thus specific conclusions from the literature is not possible to make without interpretation and cross application. If an interpretative conclusion was made it would be that pathogen contamination of groundwater is possible from drilling fluid although it would be very unlikely to cause more than natural levels of contamination in groundwater because of pathogen life expectancy in the subsurface environment.

One factor that does not seem to have been raised by the public, engineer or geologists is **pathogen leak**. The literature shows that pathogens, which may be initially trapped by a geological formation or chemical reaction with the soil, could over time be released into the groundwater. This release rate could be as long as 200 days after initial entrance and would not be detected by initial or follow up testing. If pathogen leak is an issue, it will usually occur in tightly packed geological layers.

In a general sense the transport of pathogens through groundwater is controlled by all the hydrologic properties of the aquifer, the surface properties of the virus as a function of water chemistry and the physical and chemical properties of the individual aquifer grains.[viii]

Pathogens and Factors of Contamination

Faecal coliforms, faecal streptococci, giardia and clostridium bacteria are often used as indicators of contamination in fresh water aquifers. These indicator species vary depending on the scope and substance of contamination in each specific case. In the case of the oil and gas industry migration of pathogens to groundwater would be anthropogenic because of the use of untreated water in drilling fluids. No specific work has been conducted around the injection of these bacteria. The water that makes up the drilling fluid, which will come into direct contact with the groundwater aquifer during drilling, is taken from sources in the local area. Such sources could include local rivers, lakes smaller bodies of water or groundwater and will contain some measure of pathogens. Despite the act of placing pathogens into close proximity to groundwater aquifers the life expectancy of pathogens, chemical reaction of pathogens with soil and the filtration rates all prevent pathogen migration beyond a few metres. The peer-reviewed literature indicates that pathogens coming into contact with groundwater aquifers are most often not suitable to the subsurface environment.[ix]

Almost all sources of water (treated and natural) have some degree of pathogen concentration. Distilled or completely treated water would be the only potential exception. Ground and surface water will naturally contain organic matter (including pathogens). Groundwater concerns related to human and environmental health should not focus on whether a water source has pathogens within it, but rather the concentration of pathogens and the type of pathogens. The majority of pathogens are harmless both to humans and the natural environment. Many pathogens live in soil and the intestinal track of animals. The level of pathogens can indicate the general quality of water and the likelihood that water is contaminated with a type or degree of pathogens that would be dangerous to the natural environment and to human health.[x]

Natural Removal of Pathogens

The main mechanism of removal for pathogens (especially protozoa and bacteria) is by filtration, which results in retention of pathogens at the infiltration surface due to physical clogging and retention by a biologically active layer. If the pathogen is held for a long enough time periods in the biological active layer then it will result in mortality and not represent a threat. Once this active layer is passed there is little evidence of physical removal except in fine-grained strata where pore diameters are smaller than actual organisms. The migration of injected (through drilling fluid) pathogens through a groundwater system is subject to the filtration rate of the subsurface geologic medium. Water molecules are smaller than pathogens and as a result can move through less porous material. It is possible that water will be able to move within an aquifer, but yet at the same time pathogens will not be able to filter through zones. This will depend on the pore diameter of the zone. Shallow groundwater aquifers within Alberta have pore diameters ranging from approximately 1 mm (well sorted medium to coarse grained sand or gravel) to 0.001mm (coal seams). Most shallow aquifers in Alberta are composed of glacial till which is poorly sorted with a grain size ranging from silt to gravel giving an overall low pore diameter of about 0.01 mm. The literature generally suggests that protozoa are often too large to migrate through many groundwater aquifers, bacteria are less likely to have problems of migration and viruses are generally not impacted by geological filtration.[xi, xv]

Another mechanism for pathogen removal from a groundwater system is through retardation. During transport, pathogens may adhere or adsorb to stationary particles within the rock resulting in retardation of pathogen flow through the aquifer. However, this adsorption process highly depends on the rate of flow or hydraulic conductivity of the aquifer. Aquifers with interconnected fractures or void spaces will have an increased hydraulic conductivity thereby reducing the time allowed for interaction between the rock particles and pathogens resulting in minimal adsorption of pathogens. Aquifers with very little fracturing depend on interconnecting pore space for water transport. This creates a more tortuous path for water to follow thereby lengthening the amount of time the water is in contact with the rock sediment. As a result pathogen adsorption will increase and viral removal from groundwater will be enhanced. [xv, xviii]

Increased tortuosity can be seen in most shallow aquifers in Alberta. Grain size in shallow non-saline aquifers in the Quaternary, Tertiary and Upper Cretaceous include fine to coarse sand grains, as well as gravel sized sediments. The Quaternary in particular is composed mostly of poorly sorted glacial till with a grain size ranging from silt to gravel. Varying grain sizes in these aquifers create a long tortuous path for water flow, thereby increasing pathogen adsorption. Porosity range for these aquifers across Alberta is 5-35% with and average in the low 20% range. Hydraulic conductivity ranges from 10^{-10} m/s (glacial till) to 10^{-3} m/s (medium to coarse grained sand) with and average of approximately 10^{-5} m/s. Coal seams, which are also present in the Tertiary and Upper Cretaceous, have a porosity range of 0.1-2% and a hydraulic conductivity of approximately 10^{-6} m/s. In summary, grain size distribution, porosity and hydraulic conductivity of shallow non-saline aquifers in Alberta create an environment for decreased flow velocity due to tortuous flow patterns throughout most of the aquifers. Decreased hydraulic conductivity will give more time for pathogens to have contact with and adsorb to stationary particles within the aquifer reducing the concentration of pathogens in the groundwater. [xvi, xvii]

Another important factor affecting the fate of pathogens in groundwater and relating to the natural removal of pathogens is the interaction of flow travel time with pathogen survival rates.[xii] For example, survival of bacteria in groundwater is generally thought to be limited; 90% reduction may be expected at 20°C within about 10 days, although a few bacteria can persist for 200 days or more as a result of the absence of ultraviolet light, lower temperature and less competition for nutrients. As a specific case example, the survival viability in the subsurface cryptosporidium (a protozoa) has not been extensively studied, but as oocysts (a type of cyst) are reported to survive dormant for months in moist soil or up to a year in clean water, cryptosporidium is likely to show survival rates at least two orders of magnitude longer than corresponding faecal-derived bacterial pathogens (low bonding ability and no cyst type protection mechanism). This does not mean that protozoa will migrate and pollute groundwater sources. There large size will likely prevent movement. It only means survival could occur for extended periods.

Nutrients and Subsurface Environmental Conditions

Certain conditions for the synthesis of protoplasmic constituents and the liberation of energy necessary for life processes must exist for an active microbial population to develop. The synthesis of protoplasm requires a carbon source (organic or inorganic), nitrogen, phosphorus, sulphur, an energy source, certain minerals (trace minerals) and water. The biochemical liberation of energy in the absence of light requires:

- The presence of an electron donor such as oxidizable organic compounds.
- The presence of electron acceptors such as molecular oxygen, sulphate, nitrate ferric compounds, carbon dioxide or simple organic compounds.[xiii]

Qualitatively most aquifers have a capacity to support at least a limited microbial population if there is the presence of a carbon source (dissolved organix matter, carbonates, dissolved C02), electron donors (dissolved H2 and CH4, FE2+), electron acceptors (dissolved O2, SO4 and NO3) and water supply. The availability of (or lack there of) nutrients and energy sources will place particular control on microbial growth and activity. While aquifers might be considered to support organisms which require only low levels of nutrients, most groups of bacteria are distinguished by their nutritional requirements and will not find suitable conditions. The supply of nutrient and energy sources in aquifers must be obtained from the groundwater itself, via solubilization of compounds from the rock matrix or through injected material. These dissolved inorganic compounds can be sufficient to provide energy for some pathogens.[1]

General subsurface environmental conditions such as pH, temperature, hydrostatic pressure, nutrient levels, and redox conditions all influence pathogen growth and activity.

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[1] Chemolithotrophics are a large group of bacteria that oxidize ammonia or nitrite, metabolize sulfur compounds, or deposit iron and/or manganese oxides.

Each microorganism has a pH range within which growth is possible (with a well defined pH optimum). pH can effect a microorganisms reversibly absorbed on underground particles, which cause a retardation of their transport velocity with respect to groundwater flow velocity. pH of shallow non-saline formation waters within Alberta range from 5.5 to 8. However, it is important to note that when drilling, fresh surface water that may contain the pathogens is mixed in a mud system to create drilling fluids. This mud system is kept basic at a pH range of 8.5-11 to help reduce corrosion of drilling equipment. Therefore it is possible for the pH within an environment of which the pathogens are contained to change dramatically within a range of 11-5.5 during the drilling process.

The ecology of riparian subsurface zones is enormously influenced by the heterogeneous sedimentary structures and associated complex hydrologic flow paths that mediate surface and groundwater exchanges. Sedimentary structures form a three-dimensional dynamic framework that controls subsurface flow and the vertical and horizontal exchange of water between channels and floodplains in gravel bed rivers. The underground transport of pathogenic bacteria and viruses may be described by a general equation, which considers dispersion, adsorption and biological elimination. This abstract will not go into the depth of analyzing this equation, but for those interested reference is made.[xiv] The survival time of pathogens in groundwater is different for the specific species and the specific groundwater environment. Dispersion causes a distribution of pollutants in time and space, thus their concentration decreases over time and with transport distance. The influence on pathogen migration from drilling fluid is that time, distance and concentration all need to interlink (or line-up) to produce the negative consequence of groundwater contamination from drilling fluid that contains surface pathogens.

Conclusions and Potential Importance to the EUB

From 1999 forward there has been substantial research, both in the field and on the analysis of data, relating to the subject of pathogen contamination and migration in groundwater aquifers. Previous assumptions that pathogen contamination of groundwater has been shown to not always be valid. Recent academic work reveals there are situations were concern is valid and longer-term problems can result from pathogen interactions with groundwater.

Dr. William W. Woesser at the University of Montana has conducted extensive studies on groundwater pathogens over the last thirty years. His conclusion of relevance in the last several years are:

- Viruses tend to be the largest concern for protecting groundwater. The reason for this is that bacteria and protozoa do not migrate as easily or quickly through groundwater as viruses. The result is that mortality of protozoa and bacteria most often occurs prior to a time frame that contamination of the aquifer can fully occur. Dr. Woesser has shown through subsurface Bromide mapping that viral movement most often occurs at the same rate as the average movement of groundwater. He has also noted that virus survival is not high in most aquifers.
- The underground transport of pathogenic bacteria and viruses may be described by the general equation, which considers dispersion, adsorption and biological elimination.

- The survival time of pathogens in groundwater is different for the specific species and the specific groundwater environment.

When discussing pathogens in groundwater it is important to distinguish between allochthonic pathogenic microorganisms, which enter the groundwater through contamination, and autochthonic groundwater microorganisms, which often thrive naturally in groundwater.

- Pekdeger and Matthess state that the allochthonic (non-native to aquifer) pathogenic microorganisms "are usually eliminated in the groundwater environment, but under oligotrophic (lacking nutrients and having a high dissolved oxygen content) conditions they may survive without a substantial decrease or with even slight increase in numbers during the first 1-7 days (page 49).

Conclusions

It is not possible to have a straight answer of yes or no to whether pathogens in drilling fluids can contaminate groundwater aquifers. Groundwater is unlikely at serious risk in almost all cases of drilling with untreated contaminated water. Very rare cases could exist were contamination could occur. Protozoa are more likely to be a concern from a survival standpoint than viruses or bacteria because they can adapt to the new conditions of the subsurface environment (unlike bacteria or viruses). However, unlike bacteria and viruses, protozoa are extremely limited to any movement through normal geological conditions. The only practical case of concern is where protozoa are placed into fine-grained strata where pore diameters are larger than protozoa organisms. The exact percent of drilling into this type of material in conjunction with a groundwater aquifer has not been determined.

Recommendations

An investigation on the use of shock chlorination of water tanks prior to mud being mixed (using dry Sodium Hypochloride) should be undertaken. Initial investigation does not reveal any negative impacts on the physical characteristics of the drilling fluid/mud, no significant added cost or additional time requirements. However, to date, results in the literature does not support such action based on scientific reasons.

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[xi] Yee, 2000, page 609. and West, 1997, page 149.
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Jim,
Comments at Frac Water
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Newalta is now looking for opportunities for full-scale field trials, which would demonstrate fluid performance economics and the ability to integrate the process into the logistics of completions and stimulations in the field.

Meanwhile, Calgary-based **Aqua Pure Ventures Inc.** is working with **Devon Energy Corporation** to reduce water usage in the red-hot Barnett Shale play in Texas.

The low-permeability rock requires massive fracturing, and a single frac job can consume 500,000 to a million gallons of water. Water that flows back from these treatments is unfit for surface discharge and has to be pumped down deep disposal wells. More than 150 water tanker trucks are constantly travelling the roads in a small area near Forth Worth.

"Water availability is now a constraint to well completions," and disposal options are also declining, said **Patrick Horner**, an Aqua Pure process engineer, referring to the Barnett bottleneck.

Aqua Pure's NOMAD mobile evaporator system uses a mechanical vapour recompression process to distill used frac water for re-use. Each unit consists of three skid-mounted modules: a pre-treatment module, an evaporator module and a compressor module.

Horner said about 85% of the water that flows back from a frac treatment can be recycled, eliminating the need to truck in fresh water and haul away produced water.

Besides cost and logistical concerns for producers whose wells are being fraced, there are questions about the impact of shallow frac treatments on nearby water and hydrocarbon wells.

The Alberta **Energy and Utilities Board** recently announced new pre-fracturing reporting requirements and restrictions on shallow fracturing near water wells. These steps were taken following incidents where shallow fracturing operations affected nearby oilfield wells, according to **Pat McLellan**, president of **Advanced Geotechnology Inc.**

While there are several ways of modelling frac treatments, McLellan said there is no proven, calibrated model or numerical simulator with a history of successful predictability for shallow CBM, shale gas and tight-sands fracing.

"We do not have a robust design process to confidently predict the size, shape and growth rate of the stimulated zone as a function of pressure, injection rate and time," McLellan said about shallow fracing.

To improve the design process for shallow fracture stimulations -- and to reduce the risk of affecting shallow groundwater and hydrocarbon zones -- Advanced Geotechnology is spearheading a joint industry research project.

The project just got off the ground, but new participants are still welcome, said McLellan.

The goal of the joint industry project is to develop a design process and predictive tools or models for engineering frac jobs at depths of less than 600 metres in CBM, shale gas and sandstone reservoirs.

McLellan said the aim is to reduce the economic and environmental risks associated with inefficient well stimulation treatment, design and implementation.

The first phase of the joint industry project is to review existing research, analyze recent Alberta incidents, critique modelling options and develop and test an analytical and/or numerical model.

McLellan the second phase -- which will be determined at the end of phase one -- could include simulator development, expanding existing commercial tools, a field trial with an operator or commercialization through one or more service companies.

Advanced Geotechnology hopes to have several operators and service companies signed on by September and to complete phase one by September 2007. The budget of $200,000 for phase one could rise, depending on the