Groundwater's Many Treatment Challenges

Knowing the qualities of your groundwater source, from surface water to deeper aquifers.

By Dr. Hans Peterson

In Canada and around the world communities and individuals are drilling into underground water sources that are similar to above ground lakes. Aquifers can be found a few meters to hundreds of meters below the earth's surface. Shallow aquifers (less than 30 meters from the surface) are frequently connected directly to surface water sources and are considered GUDI (Groundwater Under Direct Influence of surface water). While they are typically of excellent quality in terms of inorganic compounds, such as calcium and magnesium, hardness and total dissolved solids, these wells may contain microbes, such as *Cryptosporidium*, common to surface water.

Water is typically 10 to more than 100 years old in most deep groundwater sources. With age comes long contact times with soil and rock, with the water dissolving increasing quantities of minerals. We can learn about those minerals by simply looking at the general chemistry of what we are drilling into. The Earth's crust is formed by different types of rocks. The composition of the crust is 46.6 per cent oxygen, 27.7 per cent silicon, 8.1 per cent aluminum, 5.0 per cent iron, 3.6 per cent calcium, 2.8 per cent sodium, 2.6 per cent potassium, and 2.1 per cent magnesium.

In addition, there are other elements present in smaller quantities, such as manganese, phosphorus, sulphur and arsenic. In aquifers there are also often decomposition products of biological activity that have deposited in pockets within the soil and rock structure, resulting in water containing various levels of different compounds, such as ammonium-nitrogen and dissolved organic carbon compounds. Therefore, the type of soil, rock and deposits, as well as the time for leaching, all play important parts in determining the quality of water in aquifers.

Another factor is the level of oxygen in the water. If present, oxygen is typically accompanied by nitrate-nitrogen. Around the world there are health guidelines for nitrate, and shallow wells are sometimes contaminated by nitrate from agricultural fertilizers. The presence or absence of oxygen in an aquifer will determine how much of a compound will leach, and in what chemical state the compound will be in. A simple explanation of this is that oxidation is the uptake of oxygen, and reduction is the removal of oxygen. When oxygen is present many of the compounds that are of interest in water treatment are in their oxidized forms. When there is no oxygen present most of the same compounds are in their reduced forms. Both oxidation and reduction can occur by chemical or biological means.

In many deep wells oxygen has not been present for a long time and the compounds there are mostly reduced. This means that iron, manganese, and arsenic are all in their reduced states. Under these conditions nitrogen is mainly present as ammonium. Some sulphate typically gets converted to hydrogen sulphide causing a musty (less than 1 mg/L) or rotten egg smell (more than 1 mg/L). Reduced iron and manganese are clear and soluble. Therefore many groundwater sources when brought to the surface are crystal clear but may have a musty or rotten egg smell caused by hydrogen sulphide.

But after this water has been exposed to air for a few minutes, it becomes cloudy as the air starts to oxidize the compounds. First, the iron becomes quickly oxidized and forms large numbers of particles that soon settle out of the water. Hydrogen sulphide is also rapidly oxidized and forms particles (elemental sulphur) with manganese oxidation taking longer and may not occur unless chemicals that are stronger oxidants than air, such as potassium permanganate or chlorine, are added. Indeed, many water treatment techniques are based on oxidizing metals and hydrogen sulphide and then removing the particles that have been formed. One challenge with these treatments is that ammonium cannot be chemically oxidized and remains in the water.

Metals and hydrogen sulphide can also be oxidized by bacteria, which is the basis for biological groundwater treatment. In biological treatment inorganic particles are not allowed to form and the soluble iron, arsenic and hydrogen sulphide are taken up by the bacteria, which then oxidize these compounds internally while at the same time the bacteria gain energy from doing this. The bacteria are attached to the filtration

The Yellow Quill well water looks like the bottle on the left, as it is coming out of the ground (100 m deep well). However, within minutes reduced iron is oxidized and small iron particles are formed generating 500 million particles per L (bottle to the right). The bottle to the left is actually biologically treated Yellow Quill water and it contains no iron and extremely low levels of particles. Biological treatment takes advantage of iron bacteria to oxidize iron preventing the formation of iron particles.

Photo: Hans Peterson

material and are able to grow through these oxidation processes. Reduced compounds are literally food for the bacteria. Instead of eating a steak to get energy (oxidizing the steak), bacteria use reduced compounds to get their energy.

Bacteria don't form any particles other than their own proliferation, which sticks onto the filtration material. Therefore, instead of forming millions to billions of small particles per litre of water there is no inorganic particle formation. This is a huge advantage for biological filtration as some of those particles are like dandruff, light and extremely difficult to remove through filtration processes. Indeed, particle counts after the biological filters at Yellow Quill First Nation are fewer than 50/mL.

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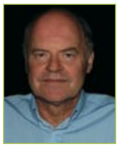
Another advantage of biological filtration is the ability of bacteria to oxidize ammonium to nitrate. This is extremely important as ammonium is causing widespread problems around the world, but it is not a compound of concern in many guidelines. This is a huge problem for water treatment plant operators. Adding chlorine in the presence of ammonium immediately generates chloramines, which have a disinfection power that is 10-1,000 times less than free chlorine. Chloramination is considered secondary disinfection and while big cities frequently practice this, they add the ammonium after they have breakpoint chlorinated (free chlorination), which is considered primary disinfection.

According to Health Canada, no community in Canada should use secondary disinfection alone, yet many rural communities do. There are concerns with how free chlorine is measured in water treatment plants as the most common method can give phantom residuals in the presence of ammonium. Indeed, if you have ammonium in your raw water you have to add 10 to 15 times more chlorine than ammonium before you reach breakpoint chlorination. If you don't, your water will not have been properly disinfected, unless you use other means to primary disinfect your water. In contrast to ammonium, nitrate does not interfere with the disinfection process and while nitrate has a health guideline even converting all ammonium in a well would be less than half of nitrate's current guideline. But, some of the ammonium is used for the growth of the bacteria and not all ammonium will end up as nitrate and it is therefore not of concern.

Differences in chemical states therefore greatly impact water treatment processes. Another example of this is that reduced arsenic is very difficult to remove even with reverse osmosis membranes. Bacteria can efficiently oxidize arsenic and oxidized arsenic can easily be removed by reverse osmosis membranes. It is therefore essential for engineers, water treatment operators, companies and governments to understand how chemical states need to be carefully controlled for optimum water treatment.

Next issue I will look at what you need to test your groundwater for, and how you need to further interpret the test data in relationship to water treatment processes. We call this "fingerprinting of groundwater," and it will allow you to quickly decide what may – or may not – work for your own well water. Currently many municipal drinking water treatment systems are constructed that never had a hope of working.



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