Ground Water Science
Science and Planning for Earth's Most Critical Resource

Using Geology and Well Construction Expertise to Improve Raw Water Quality

Stuart A. Smith, MS, CGWP and Allen E. Comeskey, MS, CPG

Challenging raw water quality frequently has a geological origin (whether officially declared "ground water" or not!). Understanding the geological origin can help those responsible for the operation of a ground-water system (or operators of a public water supply reservoir) to make decisions to either avoid or mitigate undesirable water quality. For well water supplies, sometimes a very simple strategy of changing well depth or pumping rates can avoid a problem and reduce or eliminate treatment requirements.

"Eliminating" treatment would be unusual (and not prudent, even if allowed) but hydrogeologic information and well construction planning and skill can simplify water treatment installation and operation for ground water source systems.

Some geochemistry: Experience in a variety of hydrogeologic settings shows that understanding lithologic and geochemical controls on undesirable constituents such as arsenic, uranium, or sulfide can be used to design wells so that the presence of these constituents is minimized in raw well water. In our experience, we have used geologic logging to identify (and seal off) zones that contribute to high iron, sulfide, and arsenic, and used logging to narrow the search for zones containing U in regional carbonate and shale rock and ammonia in shallow sand aquifers.

Where arsenic (As) is a problem in ground water, the source is usually found in specific layers or zones, not generally spread throughout the aquifer. As resembles iron (Fe) or manganese (Mn), in that (simplifying for illustration) the oxidized species As(V) is poorly soluble and the reduced species As(III) is highly soluble. However, As(V) is strongly attracted to FeIII oxides, especially those ferrihydrite, formed by microbial action. As(III) attaches to sulfide minerals such as pyrite.

The As-Fe relationship can be used in water treatment, of course. If sufficient Fe is present, As is also removed in conventional oxidation-bed filtration systems. The pyrite-As(III) relationship is more of a problem. Pyrite deposits (commonly found in carbonate rock and sandstones interbedded with shale and coal) can absorb abundant As. When wells are pumped, the well water can become oxidized enough to oxide pyrite (FeS minerals), releasing soluble As(III) into well water.

Sulfide is likewise a soluble, chemically reduced species. It becomes intensely insoluble if mixed with iron to form those black iron sulfides. Oxidized slightly, it becomes rather insoluble (but encourages sticky sulfur oxidizing bacteria growth). Oxidized more, it becomes soluble sulfate.

Uranium likewise has soluble and insoluble species, but the insoluble form is the reduced species and the soluble one is the oxidized species, the opposite of Fe, Mn, and As. "Roll front" uranium ore bodies form when soluble U-rich water encounters reduced ground water containing pyrite, where U deposits as an ore. Such ores can be economically important sources of U extraction. Water in the body is treated with oxidants, pumped, and the fluid run through an ion-exchange bed to extract the U. Roll-front deposits can also occur on a small scale – not enough to mine and make some money, but enough to exceed U limits in drinking water. When a well is drilled into such a zone and pumped, it is like a little solution-mining project: water is oxidized, U oxidized and made soluble, and it comes out in the pumped water.

Many other water constituents have obvious geologic origins, including radon and other radionuclides. However, these are enough for the current discussion, and some of these are not so easily solved by well design. Gases such as radon or methane tend to be diffuse in aquifer rock, and drilling deeper definitely will not help, as the source is either a) all around or b) deeper than an aquifer zone.

Geologic solution?

Drillers and geologists log drilling cuttings during drilling, classifying and recording the formation materials Figure 1.

If As, U, or S (etc) are an issue in the area, having a geologist examine cuttings can be a good investment, as the geologist (or keenly observant and trained driller) can identify minerals likely to be associated with the problems in question, and conduct field tests to confirm chemical composition.

These zones can then be cased off if other useful aquifer zones are available. The tendency in managing well construction is to stop at the first useful water, or when enough water is encountered. Sometimes it is more cost-effective to case off abundant but troublesome water, and go deeper if a better source can be encountered (see following). Borehole, casing, and grout can be inexpensive (especially on a lifecycle cost basis) compared to water treatment in some cases.

Even when it does not replace treatment, casing off constituents can lower impacts. If Fe is dropped from 4 mg/L to 1 mg/L or As from 50 µg/L to 3 µg/L, treatment systems can be smaller, backwash less laden with undesirable minerals, and filter maintenance potentially conducted at longer intervals.

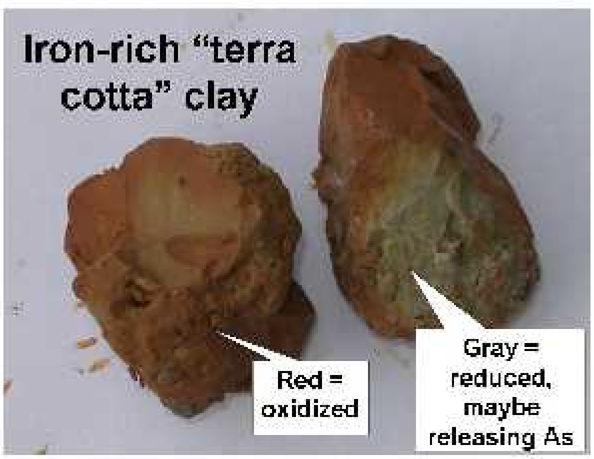
Of course, the deeper water can have its own problems: higher total dissolved solids, hardness, salinity, etc. In the glaciated Midwest, it is common for sand-and-gravel aquifers to have sand zones separated by clay layers. The deeper zones typically have higher Fe.

Two examples:

The heartbreak of uranium – Exploring for a wellfield for a hard-luck public water supply client of ours, we thought we had a real winner. Based on a tip from a 40-year-old test well log, we conducted test drilling on a property and found a highly productive carbonate aquifer zone that could supply the client – and potentially half the county. The water quality results then came back with a significant U result. We had encountered pyrite-rich zones in certain dolomite zones, so this was not surprising. U can be easily removed by iron exchange (remember that this is the process in solution mining of U ore), but the state public water supply agency was reluctant to permit the well, even when the solution was highly reliable treatment. Fortunately, in this case, the offending zones could potentially be cased off, relying on water from a deep, porous white dolomite. Far from its recharge areas, this zone was still not saline and not excessively hard or high-TDS. Unfortunately, the property was not developed due to economic reasons, but you mineral water bottlers out there: the property owner is interested in development.

Avoiding arsenic and iron – A school client was constructing a new well. As in the current well water was above the 10-µg/L public water supply standard. An iron removal system was handling the existing As. We knew that a desirable dolomite aquifer zone occurred below the zone tapped by the old school well. Again, far from its western-Ohio recharge areas, water in that zone could potentially be saline or high-TDS, but is typically low in Fe and As (usually undetectable). The clients decided to go with our advice, and gave the go-ahead for a deep-cased well. Geothermal drilling on the site showed that well drilling had to deal with abundant shallow water, so a surface casing was set and grouted and drilling commenced. Shallow water, estimated at 1000 gal/min, filled the area and drains and forced a casing size reduction, and made well grouting difficult. However, the highly skilled drillers made the completion and we conducted pumping tests. Then we held our breath, waiting for laboratory results. Our field test data were promising: Shallow water Fe was high, while completion zone Fe was below the 0.3 mg/L standard and hardness and TDS moderate. When the lab data came back, As was < 3 µg/L and Fe 360 µg/L. No new water treatment would be needed, and the existing filtration system could handle the higher well pumping rate. Oh yes, the well was very productive too. These are the times when you feel like a winner.

It seems that the shallow As was associated with Fe-rich glacial clays in shallow gravels (see Figures 2 and 3).



Look out below

Of course, the deeper water can have its own problems: higher total dissolved solids, hardness, salinity, etc. In the glaciated Midwest, it is common for sand-and-gravel aquifers to have sand zones separated by clay layers. The deeper zones typically have higher Fe and Mn. The reason is that the deeper zones are recharged and flushed with fresh, low-TDS water much more slowly than more shallow zones.

A long-standing issue in Northeastern Ohio is the imperfect interface between deeper saline and gas-bearing zones and more shallow, high-quality fresh water zones. In this situation, the solution is not so much casing as cement.

Once again, monitoring TDS while drilling is informative where shallow salinity is a possibility. Gas presence can be checked informally (for example, the bag test) and if this occurs, gas tested to define what it is. If saline or gassy zones are encountered, boreholes can be cemented back – and avoided in the next borehole.

The region is a pincushion of gas wells, some more than a century old. Geologists familiar with long-serving oil and gas wells advise that they are seldom deteriorated in the producing zone, but casing grout is likely to be incomplete in all but the most recent wells, and casings often corrode out at electrically active interfaces such as between shales or coal and sandstone. Thus, older wells that are classified as unproductive should be cemented or otherwise plugged to avoid problems with nearby water wells.

Ground water is 3-D

The vertical issue in water quality (as with well yield) is part of a three-dimensional landscape.

- Sand-and-gravel aquifers in Ohio, usually laid down rather recently as glacial outwash, are really patchy. Think of a flood, carrying trees, carcasses and more along with boulders, sand, silt and mud. Buried organic matter can serve as a nucleus for enhanced Mn in ground water, for example.
- Rock aquifers have areas of greater and lesser fracture development. More fractures typically result in more yield, but also better water quality.
- Rock aquifers in Ohio tip toward the east and southeast. A nice, clean dolomite almost at the surface in western Ohio is hundreds of feet deep by Columbus and featuring high-TDS water
- Often overlooked in water supply is using technology (directional drilling) to better use the 3-D of rock fractures and thin but areally extensive sands to improve yield and access to fresh recharge.

Planning for prevention: Some water quality issues, such as radon or methane, are not helped by casing off certain zones; but a geologist can advise on how to manage these situations. In those situations, casings can be sized and designed to vent the offending gas. Some gas is shallow, biogenic methane, and some of those zones can be isolated. In methane-rich areas where gas resources are tapped by drilling, it can useful to have the professionals document conditions (amount and features of gas, for example), and help to determine if there is an artificial cause.

Finally, well contractors and hydrogeologists experienced with running well pumping tests can help the customer to closely match well pump sizes to customer needs, avoiding oversizing pumps, excessive drawdown, etc.

Problems that come with age: As we all well know, everything ages and deteriorates: teeth, knees, ball joints, fenders – and water wells too. People who trade their trucks at the first sign of rust on the tailgate will neglect a water well for decades, and be surprised that the well, drilled in 1974, is pumping black specks and experiencing poor coliform test results. The black specks, are of course filling the filters and softeners and contributing to those whiffs of sulfide. The well needs to be cleaned.

The necessity of well rehabilitation (attempts to recover performance) and maintenance (actions to delay performance decline) have long been accepted in the oil field and, in the last 20 years, in the municipal and irrigation well markets. Domestic well owners have been slower to join the call to maintenance. However, the same mechanisms apply, whether the well is large or small. Many of these contribute to water quality problems:

- Iron, manganese and sulfur biofouling can cause bursts of discolored water and odor.
- The same Fe-rich biofouling can catch and hold As and release it as a slug of nasty water.
- Corrosive conditions (biological and electrochemical together usually) eat away at casing and well screen, resulting in sediment entering the well and poor bacterial results.
- Casing seals wear and collapse: sediment, bacteria, and other changes in water quality.
- Biofouling can even cause increases in TDS and turbidity.

A logical solution to such symptoms might be to install a series of water treatment solutions, but a place to start may be to check for symptoms that indicate well deterioration. We have the experience of a client being advised to install a complicated turbidity removal system. Upon checking, we found that the turbidity was rock particles and biofouling that could be removed by cleaning the well ($20,000 solution vs. $2 million solution).

This systems check can include a suite of water quality and bacteriological tests and a video inspection (more available than ever). Then, if symptoms indicate, clean the well. The inspection may also result in a conclusion that the well should be replaced by a new one.

Typically, a licensed water well contractor conducts well cleaning. Some specialize in this work more than others, and it is always useful to have a well rehabilitation plan written up and supervised by a professional experienced with these practices.

After a well cleaning event, discolored water and turbidity can be coughed up on an irregular basis for a long time and may result in increased backwash frequency for a while. Also, once cleaned, biofouling can be expected to return. Filtration tends to keep this out of the distribution system.

Concluding, ground-water knowledge and techniques and the arts of well construction and service are useful in minimizing the need for water treatment and improving the chances of water treatment effectiveness.

Recommended references

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