Fundamentals of Groundwater Hydrology in Richfield, WI

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In Richfield, we all get our water from private wells. After we use the water, we return most of it to the ground through an onsite wastewater treatment system (usually septic or mound system). Our Village government is acutely aware of the need to protect our water supple and has been involved in a program to monitor and understand that resource since 2004.

This article is the first of a two-part series. This article will provide you with some background on the basics of our local geology and groundwater system. A second, which will follow in a subsequent issue of the newsletter, will explain what has been learned from the first 9 years of the monitoring program.

Richfield Geology

Richfield is underlain by a series of geologic formations, listed below from the topmost (and also youngest) to the lowest (and oldest). Only the uppermost two units are important to Richfield's current water supply, so only those will be discussed below.

Geologic formation	Thickness (feet)	Groundwater setting
Glacial deposits (both sand & gravel, and clay)	5 to over 400	Shallow aquifer
Niagaran dolostone	0 to over 300	
Maquoketa shale	0 to ~ 200	Regional aquitard
Sinnipee Group (mostly dolostone)	~ 200 *	Deep (sandstone) aquifer
St. Peter sandstone	~ 250 *	
Prairie du Chien (mostly shale)	~ 50 *	
Cambrian sedimentary rocks (mostly sandstone)	0 in northwest to ~ 150 in southeast *	
pre-Cambrian basement (probably granite)	unknown	Contains little groundwater

* These thicknesses beneath Richfield are estimated, because no wells have been drilled through these formations within the village.

All the current wells in Richfield are drilled into the shallow aquifer. Figure 1 is a typical east-west geologic cross-section across Richfield and adjoining communities. It has been developed from the well construction reports which drillers file with the WI Dept. of Natural Resources (WDNR). Drawn along Holy Hill Road, it depicts the distribution of geologic materials from the Maquoketa shale upward. From it you can observe some important features.

First, the glacial deposits (yellow = sands and gravels; green = clays) are extremely varied (heterogeneous), a result of the way they were formed. Richfield has been covered by glaciers many times in the past. The most recent Ice Age is called the

Wisconsinan Age, because it is best preserved in our state. Southward moving ice advanced across the Richfield area many times in the during past periods of cold climate. When the climate subsequently warmed, the glaciers retreated. Those advances and retreats are shown schematically for eastern WI in Figure 2.

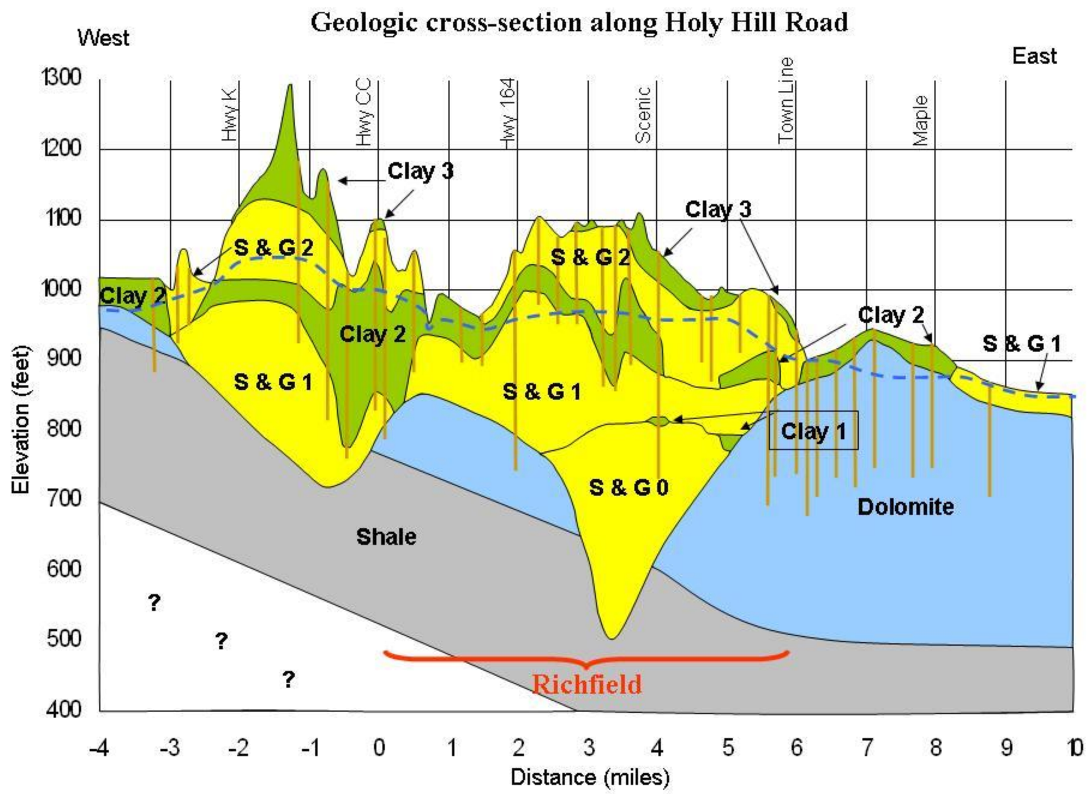

Figure 1 Geologic cross-section through Richfield (miles 0 to 6) and parts of Erin (miles -4 to 0) and Germantown (miles 6 to 10).
Yellow is sand/gravel (outwash); green is clay (till); blue is Niagara dolostone; gray is Maquoketa shale. Dashed blue line is water table, and vertical brown lines are the wells used to define the geology. Numbers on the glacial layers represent 4 advances (clay) and retreats (sand/gravel) of the ice. Depth of the bedrock valleys at miles -1 and 3 is estimated.

Glaciers are an extremely powerful agent of erosion. When they advance, they are capable of bulldozing through pre-existing sediments and even bedrock. This eroded material can be pushed in front of the ice or ground up underneath. They are also capable of picking up and carrying material up to and larger than house size like a giant conveyor belt. The bulldozed material was deposited as glacial till both in ridge features called moraines (like our Kettle Moraine). The sediment entrained within the ice settles to the ground surface as a ground blanket, called ground till, when the ice melts. Locally these tills (material deposited directly by the ice) tend to be a jumbled mix of boulders and cobbles mixed with lots of silt and clay (the material shown as "clay" in Figure 1).

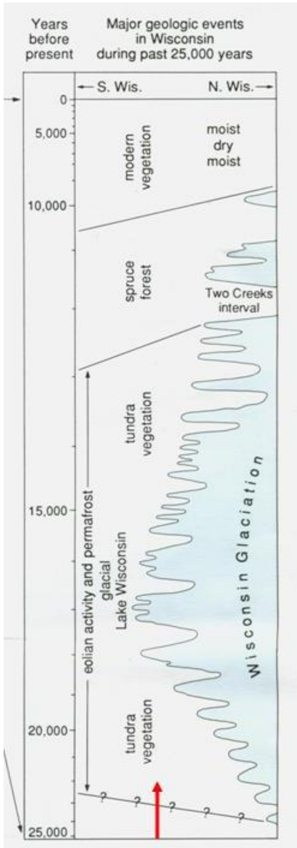

Figure 2 The relative position of the ice front during the last 25,000 years (from Clayton, Attig, Mickelson and Johnson, 1992. Glaciation of Wisconsin. WI Geol. & Natural Hist. Survey, Educational Series 36)
The light blue zone on right shows where the ice front was located on the east side of WI through time (vertical scale). Richfield, position shown with red arrow, is in a location where ice advanced and retreated many times. At least 4 of those advances/retreats are apparent in the glacial sediments beneath the Village (Figure 1).

At their maximum extent, the ice sheets are estimated to have been thousands of feet thick in our area. When that ice melted during interglacial periods of warm climate, huge volumes of water were released. In some areas, this water formed large lakes, but in our area it formed large meltwater rivers. These flowed to the southwest, toward the present-day Mississippi River, because what is now Lake Michigan was still covered with ice. Rivers approaching the size of the modern Wisconsin River flowed through what is now Richfield, carrying off sediment that had been entrained in the ice as well as carving into earlier deposits (including tills). Like modern rivers, these meltwater rivers sorted the sediment they carried, depositing coarser sand and gravel near their source and carrying finer silts and clays farther downstream. The sediments deposited by these rivers are called outwash. Because Richfield was closer to the source, our outwash is predominantly sand and gravel (the yellow units on Figure 1).

The earliest meltwater rivers also eroded deeply into pre-existing materials, forming deep valleys in the local bedrock (as seen on Figure 1 at miles -1 and 3). The total depth of these valleys has been estimated, because no wells have been drilled to the valley bottoms. The valleys were subsequently filled, first by till from the next ice advance, and then by outwash from the next retreat. This results in the second important feature visible in Figure 1, very thick sequences of glacial deposits in the center of Richfield which thin to the east and west.

Two partially filled meltwater channels are still actually visible in much of Richfield (Figure 3). The southern valley (best observed along Hwy 164 at its intersection with Monches Road) has no modern river in it. The more northern valley is followed by the modern Oconomowoc River, but the Oconomowoc isn't big enough to have cut this channel. The two valleys merge in Waukesha County, and the feature continues south-southwest toward Rock Island, IL.

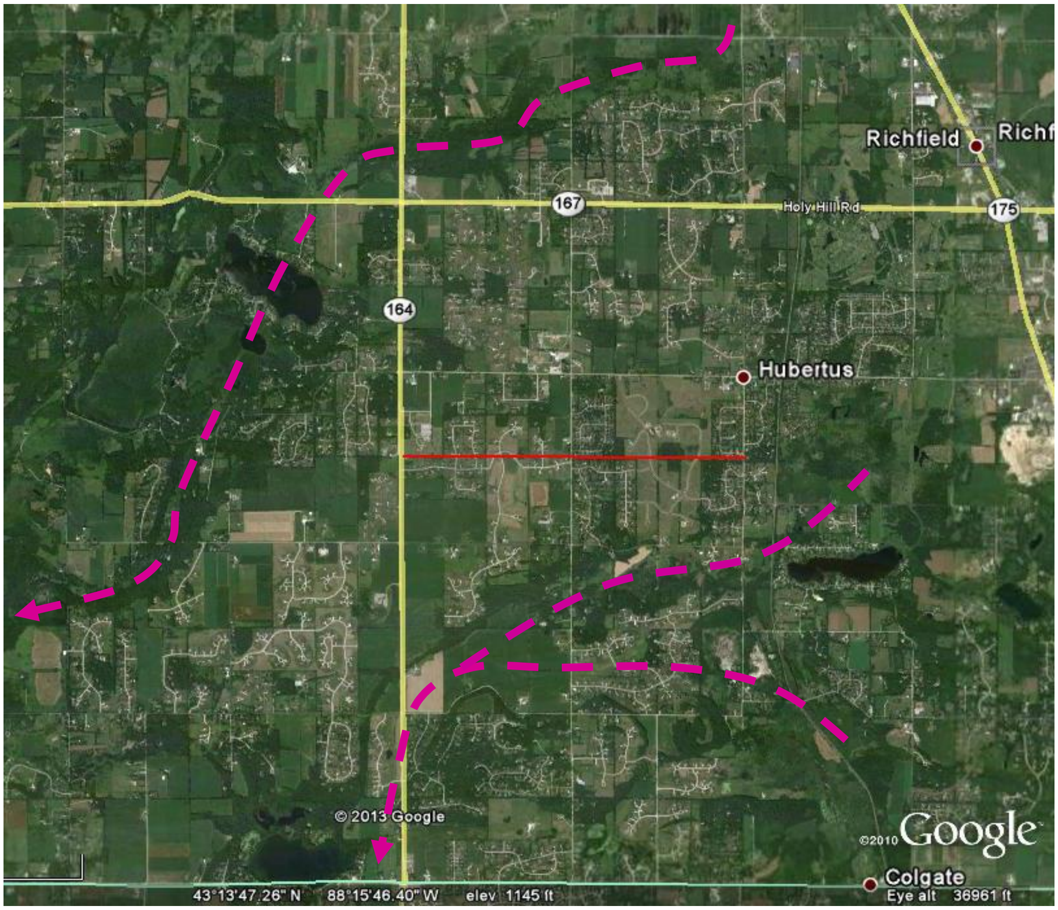

Figure 3 Satellite image showing the location of the remaining meltwater channels in Village of Richfield.
The heavy, dashed magenta lines follow the center of the two channels.
Red line is a scale bar 2 miles long, extending from Hwy 164 to Scenic Road.

The Niagara dolostone, commonly called Lannon stone, is our local bedrock. It's a calcium-magnesium carbonate rock that was deposited as sediment in shallow seas roughly 400 million years ago. As more sediment was piled on top of it, it eventually was lithified (compressed and cemented) into rock. In Richfield, as is most of Wisconsin, all the overlying rock units have subsequently been eroded away, leaving it as the shallowest rock along most of the eastern side of the state.

After lithification, the dolomite and other rock units was uplifted above sea level and warped into a structure called the Michigan Basin, a rock depression centered under the state of Michigan. As a consequence, this dolostone is currently shaped like a bowl, with eastern Wisconsin sitting on its rim. The same rock unit wraps around the Great Lakes, from Wisconsin to upstate New York, where it supports Niagara Falls (giving the unit its name). Most of it is resistant rock, producing topographic features in Wisconsin like the escarpment along the east side of Lake Winnebago and the Door Peninsula.

Richfield Hydrogeology (Groundwater Hydrology)

Aquifers and aquitards

An aquifer is a geologic unit that can hold water and also release it to a well. Water is held in pore spaces in the unit. The ability to release (or transmit) water is called permeability or conductivity and is the result of interconnectivity of pores. Thus an aquifer must be both porous and permeable. In Richfield, the glacial sands and gravels and the Niagaran dolostone are the primary aquifers.

A geologic unit with low permeability is called an aquitard and generally won't be able to transmit sufficient water to supply a well. The aquitards beneath Richfield are primarily clays and shales, but the basement granite can also be included.

Among the geologic units functioning as aquifers to Richfield, the sand and gravel tends to be more productive than the dolostone. Pore spaces are generally bigger in unconsolidated sediment, because there is no cement in them to hold grains together. The larger pores constitute between 10% and 20% of the volume in our sands and gravels, so the glacial outwash can hold substantial water. The larger pores also tend to be well-connected, resulting in our sands and gravels being very productive aquifers.

In contrast, the dolostone is solid rock. The original (or primary) pore spaces formed when the sediment was first deposited have been partially filled with carbonate minerals that cement the original grains together. Some parts of the Niagaran (such as the bottom 100 feet or so, called the Mayville Formation) do have substantial primary porosity and function as a notably productive aquifer.

The dolostone has also been cracked (fractured) when the rock was warped into its basin shape. These fractures are secondary porosity features that provide excellent conduits for water flow where they exist. Where fractures aren't present, groundwater flows through the rock's primary pores. Hence the dolostone is called a dual-porosity aquifer, which makes its productivity highly variable spatially. Wells that hit large fractures can be extremely productive, at least for a short time. Wells that don't hit large fractures can support a house well, but pumping those wells causes large drawdowns in the water level and recovery after pumping ceases is often very slow.

The glacial and dolostone units are well-interconnected in Richfield and function as a single aquifer. This aquifer is predominantly unconfined, meaning that water can infiltrate into it directly from the ground surface. The water table is roughly the position of the top of the zone of saturation within an unconfined aquifer; the pores above it are filled with air and those below are filled with water. Wells need to be drilled into the zone of saturation (below the water table) to produce water. On Figure 1, the blue line shows the position of the water table.

In areas where the flow of water from the ground surface to sand and gravel is prevented or made difficult by aquitard materials (clays in Richfield), the aquifer is called confined or semi-confined, respectively. Within the glacial materials, Richfield has areas that are locally semi-confined. The clay units are discontinuous (as can be seen on Figure 1), so water can flow around them and eventually reach the sands and gravels. Fully confined conditions do not seem to occur in Richfield.

Groundwater flow

Groundwater flows from areas where the water table is high to lower water table elevations. In Richfield, the flow pattern is shown in Figure 4. The water table configuration roughly follows the ground surface, with higher water levels in the central part of the village (along the top of the Kettle Moraine) and lower levels along the rivers that drain Richfield (Oconomowoc and Bark Rivers flow to the southwest; Cedar Creek and Menomonee River flow to the east). Richfield sits atop the subcontinental divide, so surface water flows to both the Mississippi and St. Lawrence Rivers. Groundwater does the same, although the groundwater and surface water divides don't coincide exactly.

The existence of water table maps for Richfield (like Figure 4) are one result of our community's program of monitoring groundwater levels, which will be discussed in more detail in the second part of this series. You are probably aware of the spill from a gasoline pipeline in the Town of Jackson in July, 2012. Cleanup of that spill has been made more difficult, because that town does not monitor its groundwater resources. Because no water level data were available at the time of the spill, no one knew what the natural configuration of the water table was. Measurements were made after the spill, but they were made after the aquifer had received an influx of gasoline, a second liquid which alters the elevation of the water table.

Groundwater is replenished via recharge, the infiltration of rain or snowmelt from the ground surface and through the soil and unsaturated zone. Recharge occurs throughout Richfield, but is highest in areas with sandy soils at the surface - particularly where the ground surface is either flat or contains closed depressions (like glacial kettles or storm water retention basins).

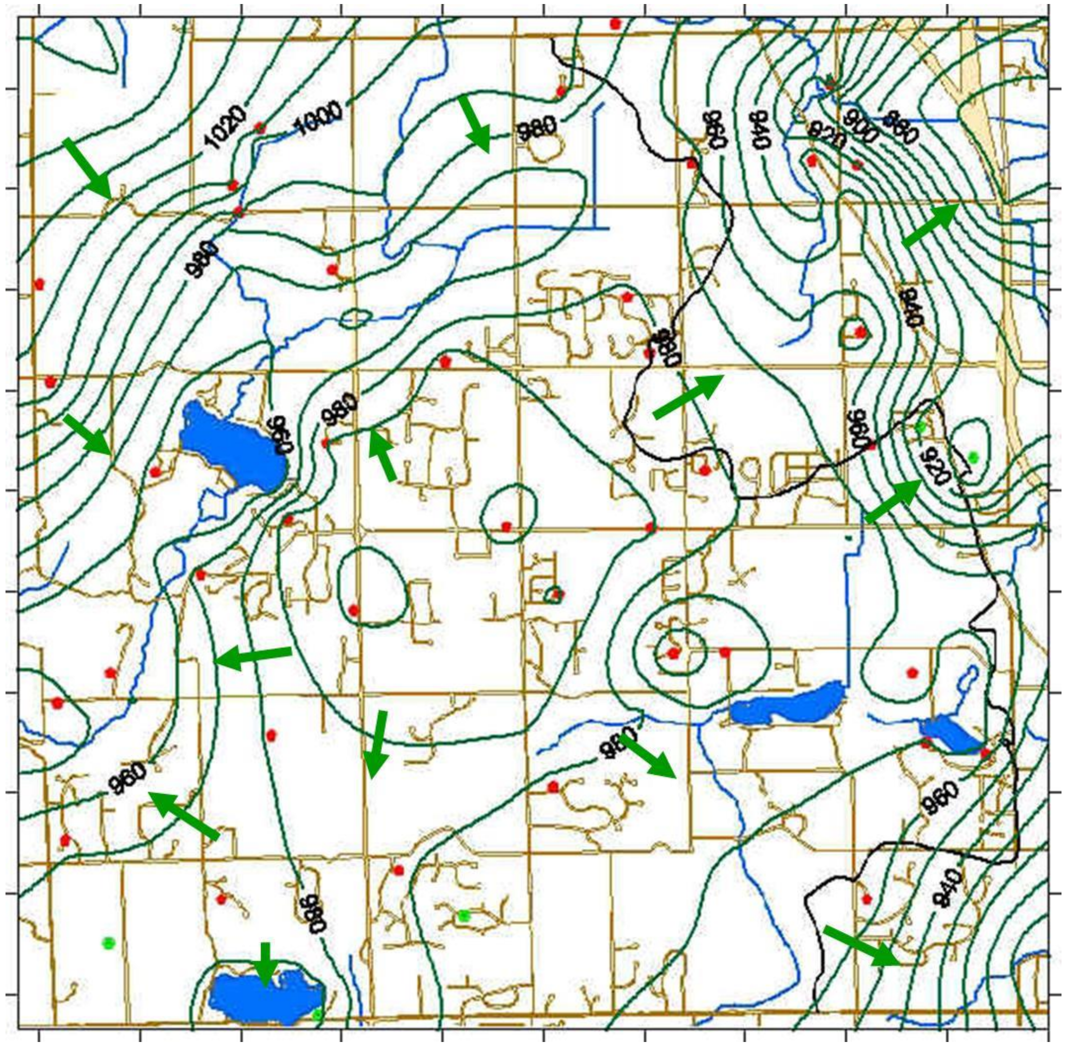

Figure 4 Representative water table map of Richfield.
Green lines are contours on the water table showing elevation in feet. Contour interval is 10 feet. Green arrows show general flow direction of groundwater.

Under natural conditions, groundwater is lost from an aquifer primarily through discharge to a surface water body (rivers, lakes, streams and ponds). Figure 4 shows the groundwater draining toward Richfield's main lakes and rivers. Lakes or ponds that have no inlets or outlets (such as Lake Five) often receive groundwater inflow on one side (the north on Lake Five) and then recharge the aquifer on the opposite side (south on Lake Five). Because Lake Five lies right on the southern Richfield boundary, we have no monitoring locations to the south and don't know exactly what water table elevations are like there.

Groundwater Quality

Groundwater in Richfield has generally good (and bacterially safe) quality, but we have not conducted a survey for contaminant other than bacteria to this time. Bacterial contamination can and does occur, and everyone should get their water tested regularly for bacteria. Water quality labs will do a bacterial analysis for roughly $30. The Wisconsin State Lab of Hygiene (www.slh.wisc.edu) provides collection and mailing kits for bacterial analysis. Look under analytical services and then tests for homeowners on their website. They also do many other types of analyses if you are interested.

The water quality problems that we do encounter in Richfield are primarily nuisances: high iron or hydrogen sulfide (H_2S; rotten egg smell) concentrations. Both are the result of the natural lack of oxygen in most aquifers and the presence of both iron and sulfur in Richfield's shallow geologic materials. The lack of oxygen makes iron more soluble in water and reduces the sulfur in naturally occurring pyrite (FeS_2) to H_2S gas. When the water is pumped to the surface and aerated at your water tap, the iron oxidizes and precipitates as iron oxide ("rust" and red color), while H_2S escapes as a gas so you can smell it. That simple aeration gets both nuisance materials out of the water. Water softeners and iron filters will also eliminate most iron issues before they reach your tap.

Our water is also quite hard (high in calcium and magnesium). This is because of the dolostone rock and glacial sediments are both rich in the mineral dolomite. Dolomite is calcium magnesium carbonate ($CaMg(CO_3)_2$) and is soluble in water. The hardness results in the precipitation of scale (mostly calcium carbonate) in your plumbing and especially at your tap and within cooking utensils. Water softeners are designed to overcome this problem. Most replace the calcium and magnesium with sodium.

Human alteration of groundwater systems

Human development of an area often inadvertently causes problems within the groundwater system, usually because we aren't aware how we are altering its balance. In terms of water quantity, putting impervious materials on the ground surface, like buildings and pavement, will reduce the amount of recharge to underlying aquifers, as will the tiles and ditches used to drain farm fields. Drilling and pumping wells will increase discharge from aquifers, and coupled with the impervious surfaces this will reduce the total groundwater supply. In Richfield, most of the water we pump from our wells is returned to the aquifer through our onsite wastewater treatment systems, so in our village our biggest impact is through reducing recharge. Even there, the use of roadside ditches (instead of storm sewers) and unlined retention ponds to collect runoff enables some portion of the runoff from impervious surfaces to recharge the groundwater.

In terms of water quality, it's a good rule of thumb that whatever we put on the ground surface ends up in our groundwater. Applications of fertilizers, manure and pesticides should be limited to what will be used at the ground surface. Overapplication will result in adding the nitrates from fertilizers and manure or the toxins in weed or insect killers to our water supply. Those chemicals will first enter the groundwater directly below where they are applied and will then move with the flow of groundwater down the slope of the water table.

Two other sources of contamination - road salt and human waste - are probably the most widespread of our chemical alterations of our water supply. Road salt is completely soluble in the water it generates by melting ice and snow. Rather than disappearing after it done its melting, it simply dissolves and is carried by the water, either as runoff or as recharge to our water supply.

Salt is sodium chloride. The sodium reacts with geologic materials in a process called ion exchange, getting held by clays while releasing calcium and magnesium. Its primary effect, therefore, is really to increase our water's hardness. Chloride, on the other hand, does not react with anything in the natural geologic materials, so it stays dissolved in groundwater and ends up in our water supply. The only way to remove it from water is either through distillation or reverse osmosis treatment. In the long run, it will be far simpler and safer for our water supply to simply use less salt (and more sand) on our roads in the winter.

Human waste (plus any pharmaceuticals we flush down the toilet) ends up in our water when it passes through poorly maintained or overused septic or mound systems. It's crucial that everyone maintain their wastewater systems. Septic tanks should be pumped out every one or two years, and if the drainfield begins to spill into nearby ditches or to smell like sewage, it will need to be replaced or upgraded.

Onsite wastewater treatment systems are simply not designed to remove pharmaceuticals from the water that infiltrates into our aquifers from them. Even though prescription bottles may tell you to flush old medicines down the toilet, we now know that this is an unacceptable method of disposal. Old medicines need to be taken to toxic waste collection areas from which they will be incinerated.