The Richfield Groundwater Monitoring Program: Background and Results from the First 10 Years

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Executive Summary

In order to assure that the groundwater resource that supplies all of Richfield residents with water will always be sufficient, the community in 2004 developed a unique, three part program to protect its water supply. The program involves: 1. land use planning to minimize likely groundwater impacts, 2. bimonthly monitoring of water levels in over 40 private wells and over 20 streams and lakes, and 3. an ordinance that requires new developments to assess their water needs in advance and then to project their likely effects on the water supply.

After the first 10 years, it can be seen that the program is working. Groundwater levels in Richfield's shallow aquifer (sand and gravel plus dolomite) have risen an average of 3 feet from 2004 to 2013. Almost all of the wells that have been monitored since 2005 had higher water levels in 2013 than they had in 2004. The monitoring allows us to show that the few heavy water users that were in place in 2004 have not had a discernible effect on nearby wells in the monitoring array. With one exception, the post-2004 subdivisions have also not had an impact on nearby monitored wells. This is not a surprise, because most of these developments are not yet close to full buildout and their maximum expected water demand.

One potential trouble area will need a longer monitoring record to determine what is happening and why. The southeast quadrant of Richfield plus the area along Hwy 175 north to at least Hwy 167 has had water levels increase much less than the Village average in the last 2 years. Data from some wells newly added to the monitoring array suggest that there could be localized and anomalous declines in water level. The declines appear to result from a combination of new pumping and possibly drainage from the shallow aquifer to the deeper sandstone aquifer. Continued monitoring and possibly adding some wells to the array will be needed before we can be sure.

The monitoring program has produced a wealth of information on the quantity of water in Richfield's shallow aquifer, enough to demonstrate there is no need to consider a municipal water supply. Expanding the program to measuring a few representative chemical parameters periodically would also assure residents of Richfield of the viability of their water supply's quality.

Introduction

All of us living in Richfield rely on groundwater from private wells as our source of water supply. There is no direct way to observe what's happening in our underlying groundwater aquifers, because the water is underground. There is also no outside governmental agency that checks on groundwater conditions in private wells or on any regular schedule. The Wisconsin Department of Natural Resources (WI DNR) and the Wisconsin Department of Commerce, Agriculture and Consumer Protection (DATCP) do archive the well construction reports which drillers file at the time a well is constructed. The WI DNR site contains most records for wells drilled after 1988, while the WI DATCP site contains logs for selected wells drilled between 1936 and 1989. Those records are available online at (http://prodoasext.dnr.wi.gov/inter1/spinvent$.startup and http://datcpgis.wi.gov/WellLogs/, respectively) and do contain information about the static water level at the time the well was drilled, but these agencies do not follow up to see if the water levels change in response to development or changes in weather patterns. Therefore, if Richfield residents wish to protect their water supply, we will have to monitor that supply ourselves.

Most towns in Wisconsin and some municipalities (cities or villages) rely on private wells for their supply, but very few have taken the initiative to monitor their water supply. The City of Mequon in Ozaukee County has probably been the most active in observing its water supply. Beginning in 1970, Mequon has measured water levels in several dozen wells monthly. The results are revealing. Groundwater levels in parts of Mequon dropped over 150 feet between 1970 and 2000 (Well 4 on Figure 1). This considerable decline is due partly to increased demand for water from new developments in the southeastern part of the city and partly because the dolomite aquifer being pumped is confined by over 100 feet of clay-rich glacial till in Mequon. As a result, there is very little direct recharge to the aquifer from rainfall or snowmelt. The high clay content of the till precludes the effectiveness of onsite wastewater treatment systems (septic and mound systems), so Mequon residences and businesses are connected to sewers of the Milwaukee Metropolitan Sewerage District (MMSD). In effect, Mequon was pumping more and more water out of the ground, while returning virtually none of it.

The result was that water levels were dropping and the area underlain by a declining water table was expanding until 2000. In 2000, portions of Mequon began to receive Lake Michigan water from the Milwaukee Municipal Water System. As you can see in Figure 1, the water table in parts of the city rebounded for the next 5 to 7 years. After that, the water levels either stabilized or started to decline again as the demand for water from further development continued to rise. Wells in areas away from the concentrated development (wells 22 & 24 in Figure 1) showed a slower decline and also no rebound, because they are away from the area where city water has been supplied.

The Mequon monitoring program is focused on the areas of most concentrated development. There are only 3 wells monitored in the western third of the city, but they have shown very little change in water level through time (see well 11 on Figure 1).

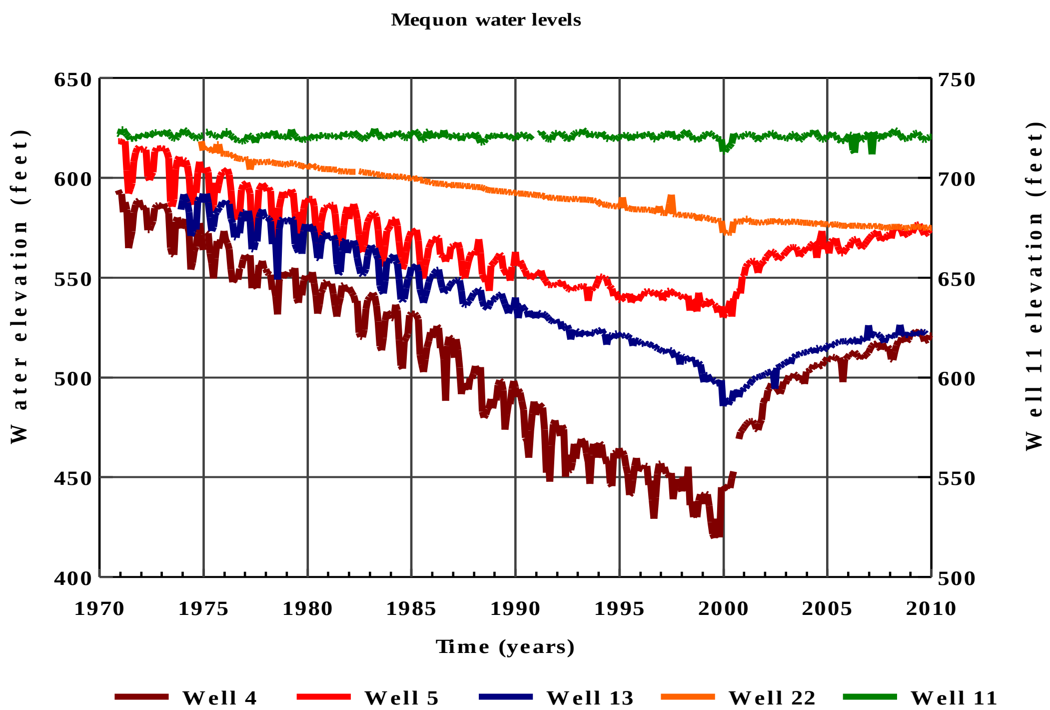

Figure 1 Historical groundwater levels in private wells in Mequon, WI Wells 4 and 13 are near the center of a cone of depression in the water table which developed due to residential and commercial pumping without return of water to the aquifer. The cone is centered near the intersection of Port Washington and Donges Bay Roads. Well 5 is about a mile to the west, and well 22 is about a half mile south. Water elevations for those 4 wells all refer to the axis on the left. Well 11 is 6 miles to the west, and its levels are shown on the right hand axis. Treated wastewater is returned to the aquifer in this western part of Mequon.

Geologic conditions in Richfield are quite different from those in Mequon. Most of our village is underlain by sand and gravel deposits which serve as a more productive water supply then the dolomite (see article entitled Fundamentals of Groundwater Hydrology in Richfield, WI on this webpage). Under most of Richfield the water supply aquifers are in direct or nearly direct contact with the ground surface, so our aquifers are either unconfined or at worst semi-confined. In these areas, we shouldn't expect to see drawdowns (declines) in groundwater levels like those Mequon experienced. However, the sand and gravel becomes thin in eastern and far northwestern Richfield. There most water wells use the same dolomite aquifer that Mequon residents use.

In addition, most residents in Richfield treat their wastewater through septic or mound systems and return that treated water to the same aquifer which supplies us. As a consequence, in most areas the water pumped out of the ground is largely balanced by the water returned.

Richfield's Groundwater Protection Program

The Mequon case above demonstrates that medium density residential and commercial development can put enough stress on a groundwater supply to cause substantial drawdowns in the dolomite aquifer. This obviously has repercussions. In locations where the water table has dropped over 100 feet, any older well that had been drilled deep enough to have only 125 or so feet of water in it could go dry during droughts or if additional development occurred, and many in Mequon had to be deepened. The case also demonstrates that the only way to know what the groundwater response to development is would be to monitor water levels through time.

Richfield leaders were and are aware of the potential for undesired impacts to our groundwater resource from unchecked development. To prevent such impacts from occurring, first the Town and now the Village Board have adopted and enforced a three part protection program. It consists of:

1. Land use planning,
2. Establishing and maintaining a monitoring program, and
3. Enacting and enforcing a groundwater protection ordinance.

This comprehensive groundwater protection plan was a key component the the State's approval of Richfield's application to incorporate as a village. We are one of a very few incorporated municipalities in Wisconsin without municipal water and sewer, because we were able to demonstrate we don't need wither. The components of the plan are explained below.

<u>Groundwater Protection 1 - Land use planning</u>

The Town of Richfield developed a comprehensive land use plan in 2004. The plan called for future growth to be primarily low to medium density residential with some low-water-demand commercial and industrial, coupled with retention of as much land in agriculture as possible. In addition, the environmental corridors already in place were to be retained. All water would be supplied from private wells, and wastewater would primarily be returned to the ground through onsite treatment systems (septic and mound systems). In places where the density of homes precluded the effectiveness of individual wastewater treatment systems, the spent water would be collected into holding tanks (for transport to a wastewater treatment plant) or communal septic systems and drainfields.

For clarity, these communal septic systems are not municipal sewer systems. They merely collect the spent water from multiple locations and deliver it to a site (usually nearby) where it can be safely treated and returned to the ground. In contrast, a municipal sewer system will transport the spent water to a wastewater treatment plant, from which, in Wisconsin, the effluent is almost always discharged to surface water.

New developments would be required to conform to the land use plan and also demonstrate what their groundwater impacts would be (discussed later under GW Protection 3). The comprehensive land use plan does allow for commercial, light industrial and higher density residential development on the east side of Richfield, along the WI Highway 175 and US Highway 41/45 transportation corridor. Much of this area is underlain by only the dolomite aquifer, the same one in which Mequon has seen large drawdowns. As mentioned above, Richfield's dolomite aquifer is much less confined than that in Mequon, and we will also return our treated wastewater to the thin glacial sediments above it. Consequently, it is unlikely that Richfield will ever see the drawdowns that Mequon has. However, to prevent that, Richfield's Protection Plan has two more safeguards below.

Groundwater Protection 2: Long-term Groundwater Monitoring Program

Following the lead of Mequon, Richfield's leaders agreed in late 2003 to develop a program to monitor water levels throughout the community. The process was started with a grant from the WI DNR that allowed the author and his students at UWM to initiate the program. A public meeting was held seeking home owners who would volunteer to allow us to measure water levels in their wells periodically (bimonthly).

Our goal was to get roughly 36 wells, one per section (square mile) in the community for monitoring purposes. The public response was excellent; at least 50 homeowners plus several businesses and government entities volunteered. We selected as broad an array of sites as we could, but had to turn a number of volunteers down, usually because they were in close proximity to other volunteered wells. Figure 2 shows the locations of the wells. The program started with 37 wells. Since then, 4 homeowners have withdrawn from the program, but another 10 have joined. The end result is that there are currently 43 wells being monitored bimonthly. Of those 40 are water supply wells, and 3 are dedicated monitoring piezometers (wells constructed for monitoring only). The added wells have been to fill gaps in the original coverage or to add detail in areas where it is needed.

As you can see, there are still parts of Richfield without representation in the program. The most obvious gaps are in the extreme northwest, northeast and southeast corners, although there are a few sections in the interior of the Village without monitoring sites. Mostly these are areas where there are few, if any, homes. However, if you live in one of the unrepresented areas and would like to participate in the monitoring program, contact me (preferably by email: aquadoc@uwm.edu).

In addition, we also measure water levels in streams and lakes. All the large lakes and flowing streams in Richfield are groundwater discharge locales. Groundwater flows to the surface in these low areas. So streams and lake levels are actually water table levels. We use them to augment the well data in generating water table maps.

In return for participating, volunteers get their water tested for bacteria every second year. Typically water samples will be collected in the spring of even years. In our last round of samples (April, 2012), all the tested wells were free of any bacterial

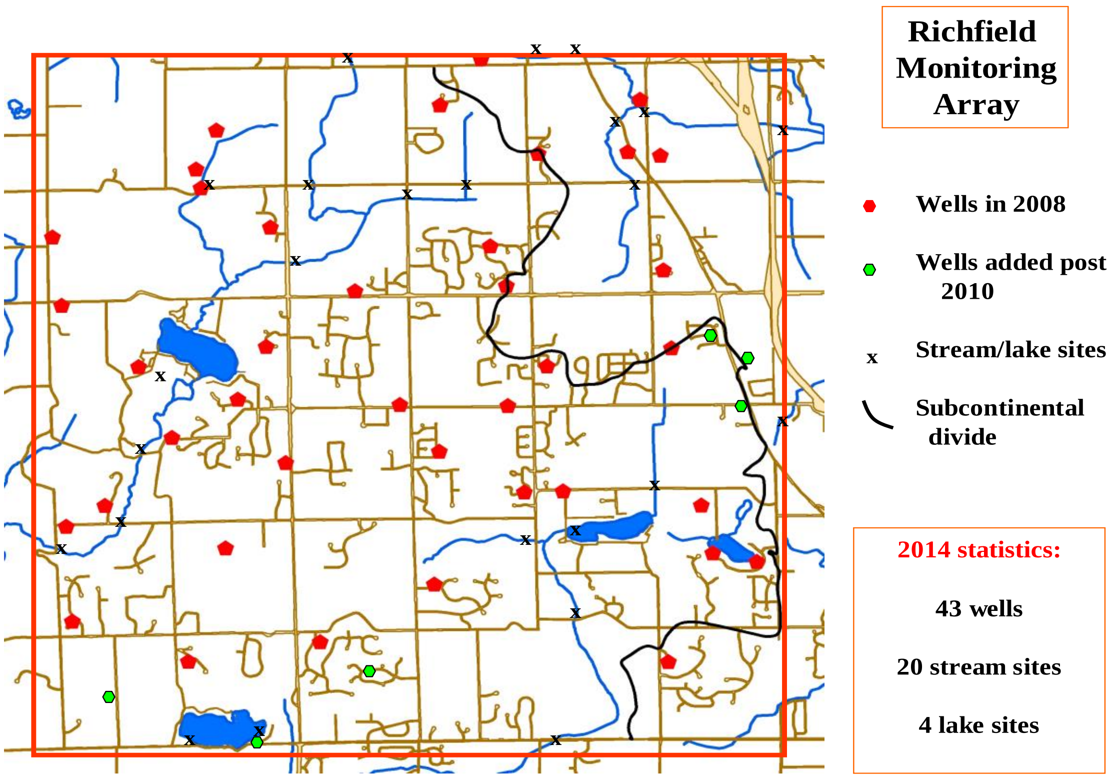

Figure 2 The Richfield Monitoring Array in early 2014
The red line roughly highlights the boundaries of Richfield.
The road system (brown lines) shown on the map may not include your road, because it shows the roads the existed in 2000, the latest GIS data the author had access to at the time this article was prepared. For scale, the continuous roads running north-south or east-west are sections line roads, so they are a mile apart. The subcontinental divide separates the Great Lakes surface watershed (to the east) from the Mississippi River watershed (to the west).

contamination, an indication that Richfield's groundwater is not currently experiencing contamination from the ground surface or treated wastewater returns. Two of the volunteer sites did show bacteria in their outdoor water spigots, but not in the water coming directly from the well. This suggests that the potential for contamination of your home's water supply exists, usually from surface sources. Therefore, it's a good idea for everyone to get their water tested for bacteria periodically. This can be done through a local water testing laboratory or the State Lab of Hygiene in Madison at http://www.slh.wisc.edu/services/. Click on Tests for Homeowners.

The monitoring program needs to be continued into the future, because that's the only way we can be sure what's happening to our water supply. Results from our first 10 years of monitoring are presented later in this article. At present, the only water quality parameter tested for is coliform bacteria. The program should probably be expanded to monitor a few water quality indicators, such as chloride (salt) and nitrate (fertilizers, manure, septic or mound effluent) levels.

Groundwater Protection 3: Richfield's Groundwater Protection Ordinance

Richfield's leaders have recognized that monitoring by itself can only see impacts to groundwater after the fact, when it is too late to prevent problems. So they have developed a proactive step to anticipate what the effects of future development might be on our water supply. The text of the Groundwater Protection Ordinance is provided as a hyperlink on the webpage with this article.

In short, it requires that each new development obtain a Groundwater Protection Permit from the Village before being approved. The process requires that the developer conduct an analysis of the groundwater system under the proposed development and then provide the Village staff with an analysis of what the development's impacts on the water supply will be and that they meet specific criteria.

The developer is required to provide a conservative (upper limit) estimate of the total water that will be needed daily once the development has been fully built. This includes the estimated water to be used by residents or commercial/industrial entities, for irrigating vegetation in the communal areas, and for recreation and aesthetics (filling swimming pools, running decorative fountains and the like). If the developer intends to use well water to keep ponds on the site filled, that needs to be included as well. In addition, the developer needs to present an analysis of how the new structures, pavement, runoff conveyance (curb & gutter, roadside ditch) and storm water detention or retention ponds will modify recharge to the aquifer beneath the site.

Once all the above is presented, a conservative, net daily water demand (water pumped out + recharge decrease - water returned) needs to be calculated. This is combined with the site design for wells (individual wells for each lot, or communal wells to serve multiple buildings) to calculate what the maximum drawdown will be at the development's boundary. To obtain a groundwater permit, that maximum drawdown in the glacial/dolomite aquifer must be less than 1 foot for an average day. It must also be shown to be less than one half (0.5) foot in that aquifer beneath the nearest perennial surface water body. If either of these criteria is not met, then the developer will be asked to redesign the proposed site until it is compliant. Such reworking can include reducing the number of proposed structures, minimizing non-essential use of water, maximizing treated water return, or even going to the deeper sandstone aquifer. The goal of the ordinance is to protect current and future neighbors from being impacted by more than a foot or two of drawdown at their property boundary. *[It should be noted that generating one half foot of drawdown in the aquifer under a stream or lake does not mean that the water level in that water body will drop one half foot. The surface water level will drop much less than one half foot.]*

One potential shortcoming of the ordinance is that it is only applied to new developments at the time of their design and approval. At present, it doesn't address impacts from changes in water usage in areas developed before the ordinance.

Results of the First Ten Years of Monitoring Richfield's Groundwater

The monitoring program allows us to determine the physical state of our groundwater supply and to answer questions such as: Is the protection program working? Are there areas where groundwater levels have been effected by new developments or large water users? What, if any, action should the Village take? Let me try to answer those questions by presenting the program's results.

<u>Groundwater Flow Pattern and Water Budget</u>

The depth of the water table below the ground surface in water supply wells ranges from 12 to 164 feet, not including one artesian well where the water level can be 8 feet above the ground. The smaller depths occur in wells near surface water bodies (on low land), while the higher values occur on high ground.

In addition to measuring the depth to water in each well and stream, we have also surveyed in the absolute surface elevation at each site. Subtracting the depth to water from the surface elevation allows us to determine the elevation of the water table at each site and then present that information as a contour map. Figure 3 is a representative water table map from December, 2011. The pattern of flow doesn't change notably through time, although the elevations of the water table do. Typically, the water table has high elevations under surface hills and low elevations which coincide with surface water bodies. It also has about 150 feet less relief than the ground surface does.

A water table map allows us to determine the direction of groundwater flow, because groundwater flows down the gradient on the water table. In Richfield, our highest groundwater elevations are in the center of the Village, near Village Hall at the intersection of Hubertus Road and Hillside Drive (Figure 3). Flow is radially outward from that high until groundwater discharges in the Oconomowoc River and Friess Lake to the north and west, Cedar Creek to the northeast, and the Bark and Menomonee Rivers and Bark and Amy Belle Lakes to the southeast. Along the east side of the Village, groundwater is also flowing into Germantown to the east.

In general, the bulk of the groundwater we use in Richfield originates in Richfield, as recharge from rain and snowmelt through the ground surface. The only place where groundwater is entering Richfield is from the northwest. That inflow supplies several square miles of Richfield before it discharges into the Oconomowoc River and its tributary, the Coney River.

With the exception of this northwest corner, Richfield is in complete and total control of its own water supply. This is a good thing, but it also means we must have the will to protect that water supply. We need to protect the quantity of water, which our groundwater protection plan is intended to do, but we also have to guard against contaminating the water with chemicals we put on the land surface (road salt, fertilizers, pesticides and surface spills of oil derivatives and cleaning chemicals).

The much steeper gradient (contour lines closer together) along the east side of the Village indicates that the shallow aquifer system is less conductive there. As pointed out earlier, there is very little conductive sand and gravel in that area, so the shallow aquifer is primarily dolomite. Dolomite bedrock is less conductive than the unconsolidated sand and gravel, so the water table map is telling us that this part of the Village has a less productive aquifer system.

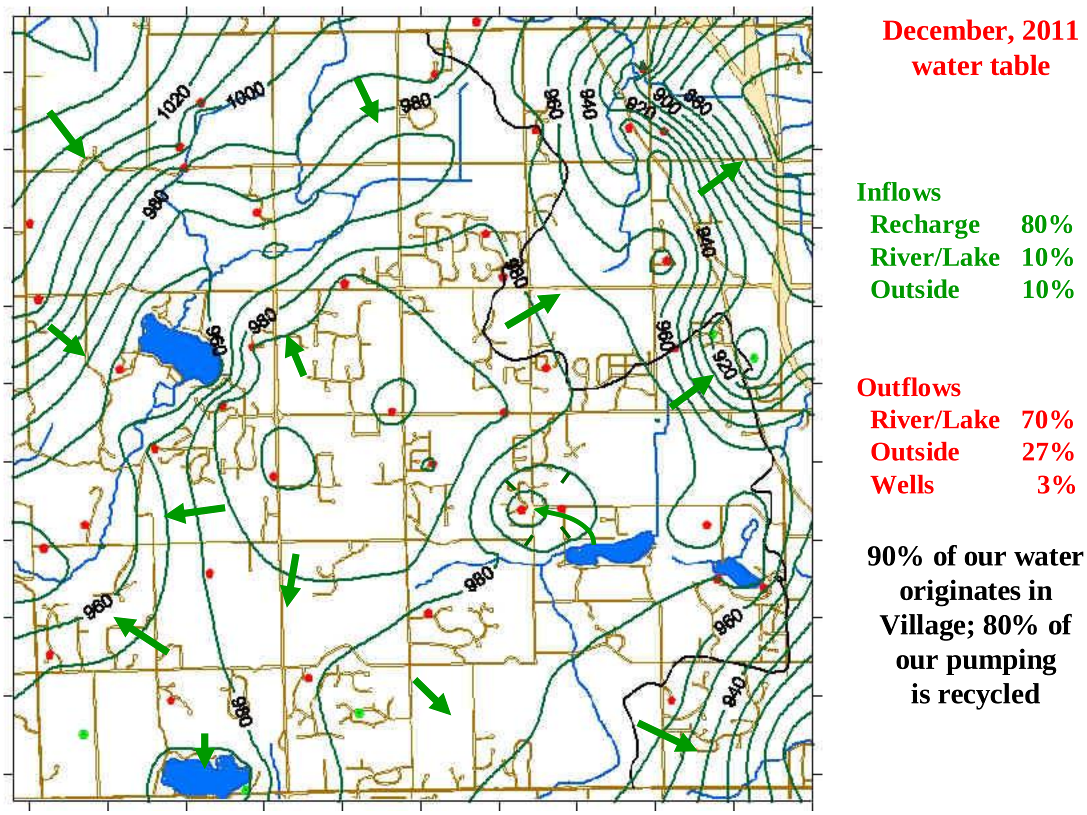

Figure 3 Water table map and groundwater budget for Richfield in December, 2011 Green lines are contours of equal elevation on the water table. Contour interval is 10 feet. Groundwater flows from high water table to low. Green arrows added to show basic directions of flow. Note that groundwater can flow underneath the subcontinental divide (black line across eastern Richfield), which separates the surface watersheds of the Mississippi River (to west) and the Great Lakes/St. Lawrence River watershed (to east). Note also that the area just northwest of Bark Lake is a groundwater depression into which groundwater is flowing.

We have constructed a groundwater flow model to determine the water budget of Richfield. The model is built to include the underlying geology, the surface water system and then the inflows (mostly recharge) and outflows (streams, lakes, wells) from the aquifer system. The model has been calibrated by adjusting unknown properties (conductivity of the geologic materials) until it reproduces the water table pattern shown in Figure 3 and measured groundwater discharges in a number of streams. Once that is done, the model can be queried to determine the magnitudes of the water flowing through the system: the groundwater budget. While this budget changes a bit from wet to dry periods, typical values are shown on the right of Figure 3.

Within Richfield, the average annual recharge is about 6 inches per year, much smaller than our average annual precipitation of about 37 inches per year. Only 16% of our annual precipitation percolates all the way to the water table. The rest either runs off to streams, or evaporates or is used by plants before it reaches the water table. Despite the seemingly small annual recharge rate, the average daily recharge for the entire Village is more than 9 million gallons per day (Mgd). The apparent disparity between the two numbers is due to the huge size of the Village (36 mi^2).

Recharge is far and away the largest source of water for Richfield's groundwater (Figure 3), constituting 80% of inflow. Another 10% is groundwater flowing in from outside the Village. The remaining 10% is drawn from surface water bodies., mostly wetlands, but also lakes and streams in areas where pumping is occurring.

On the outflow side of the budget, the bulk of the groundwater discharges either to surface water bodies (70%) or flows into neighboring communities (27%, Figure 3). The net pumpage out of all our wells (pumpage minus return) is estimated to be only a little over 300,000 gallons per day. We probably pump as much as 1.5 Mgd out of the ground, but something on the order of 1.2 Mgd flows back into the ground through our septic and mound systems. These pumping amounts are only estimates, because almost none of the wells in Richfield are metered. Only a few high capacity wells, such as those at the Kettle Hills golf course and the Reflections Village development, are required to report their pumping to the WI DNR.

At present, we are pumping only a small portion of the average daily recharge out of our aquifer. As long as Richfield continues to follow our comprehensive land use plan, with future development being primarily low and medium density residential, our aquifer system will be able to continue to supply our needs.

Historical changes in groundwater levels

1. Patterns of groundwater level changes at specific locales.

Groundwater levels do change through time, largely in response to natural conditions, but sometimes due to human pumping or paving. Figure 4 shows the history of water elevations in my own well, where I have been measuring water levels since shortly after I moved to Richfield. I try to monitor the well weekly, although vacations and weather sometimes prevent my achieving that frequency.

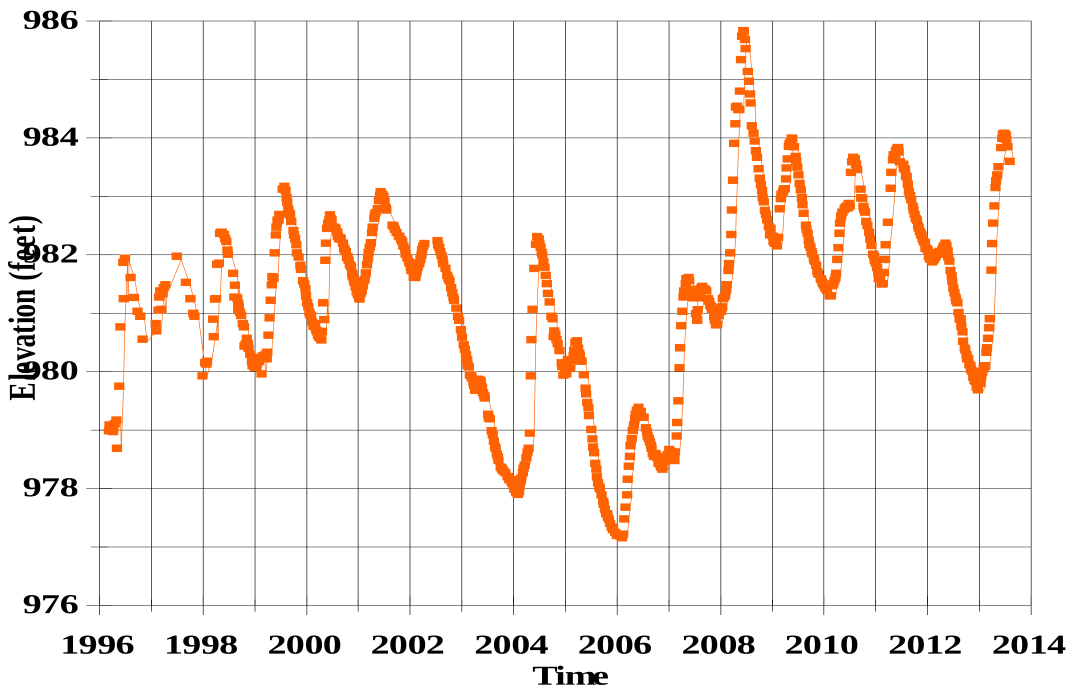

Figure 3 Historical water elevations in the author's well
The vertical lines are drawn on January 1 of each year, with the even year labels centered under their line. The space between the vertical lines labeled 2006 and 2008, for example, represents January 1, 2006 to January 1, 2008. Readers can visually interpolate within that time frame, with the water level cresting around June 20 in 2006.

The record in my well is typical for water levels throughout Richfield. Our primary recharge occurs when the ground thaws during the annual snowmelt, generally in March. The water level in my well typically peaks between 3 and 4 months later, in mid to late June. The water table is around 123 feet below the ground surface, which means that it takes months for the bulk of the annual recharge to reach it after the spring snowmelt. In wells where the depth to water is much smaller, the response to recharge is much quicker.

There is a rise in water level in the well each year which can range from less than 3 inches (2003 and 2012) to 4 to 5 feet (2004, 2008 and 2013). The peak elevation occurs when the annual recharge reaches the water table. After that there is a slow decline in water elevation throughout the summer, fall and winter. Once the ground starts to thaw, sometimes with a January thaw, followed by subsequent refreezing, water begins to work its way into the ground. The water table starts a slow rise as early as January (Figure 3). This is due to early recharge having reached the aquifer in other nearby areas where the depth to water is much smaller. The bulk of the recharge local to my well doesn't reach the water table until June, which is when the water level crests.

Over longer periods of time, the water elevation has varied from 977 to 986 feet, a range of nearly 9 feet, with lows occurring in dry years and highs in wet ones. When we have 2 wet years in a row, such as 2007 and 2008, the water elevation rises dramatically. In dry years like 2003, 2005 and 2012, the water table throughout Richfield drops notably. This can actually cause problems with your well. If you and your neighbors are irrigating your plants heavily and your pump is set relatively high in the well, the water table can drop below your pump. The well is not actually dry, but this situation may cause your pump to burn out.

There is also correlation between water level in different wells and in surface water bodies (Figure 4). The water level in my well (Number 23 in the monitoring array) is measured weekly. Well 49 is a piezometer built to serve as a dedicated monitoring site; it has no pump to affect water level and it has been fitted with a transducer that measures water level every 4 hours. The average depth to water in these 2 wells is about 120 feet in 23 and 11 feet in number 49. In addition, residents along Lake Five have been measuring lake water levels during the past 3 summers.

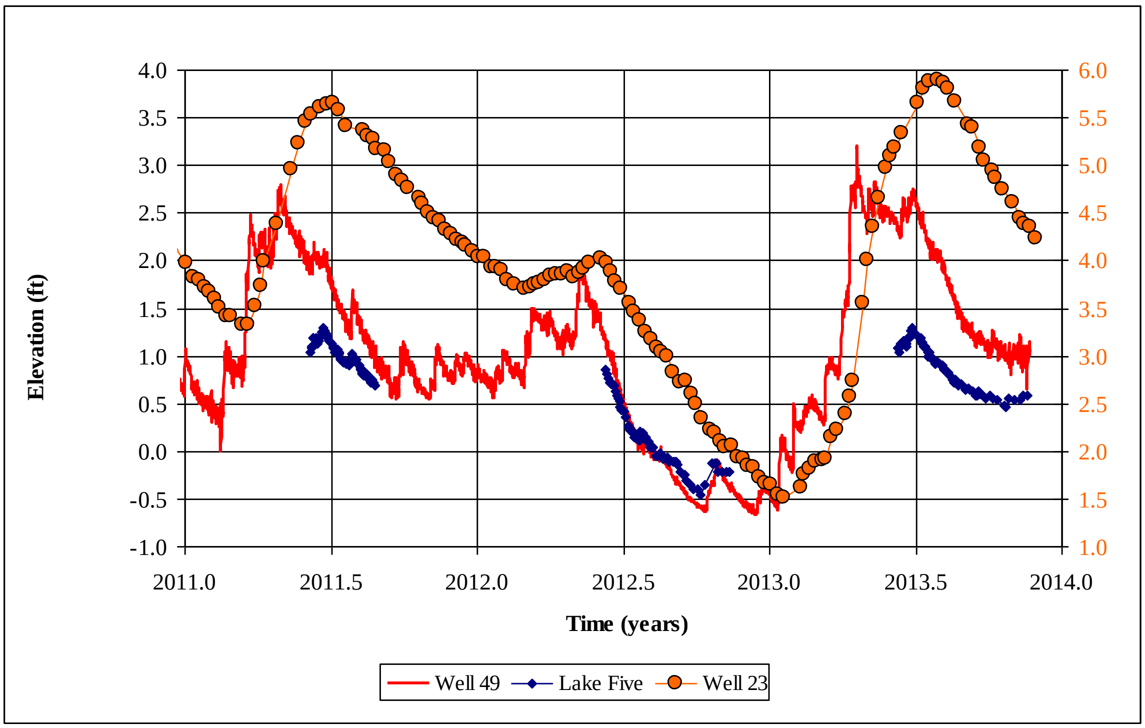

Figure 4 Comparison of relative water elevations in wells and a lake
Water levels over the past 3 years in Lake Five and two frequently monitored wells are shown. Lake Five level has only been measured during the summer season. The lake and Well 49 levels refer to the left vertical axis. Well 23 uses the right axis, which is displaced to allow better comparison.
Location of the wells is shown on Figure 9 later in this article.

As can be seen in Figure 4, water levels in all 3 locations generally parallel each other, rising in the spring and then falling the rest of the year. This demonstrates that this lake, which has no surface inlet or outlet, is directly connected to the groundwater system. Other lakes will also show a similar connection, but they are not monitored frequently enough to show that correlation.

The responses to precipitation in the lake and Well 49 show exceptional similarity, even though Well 49 is nearly 6 miles north of the lake (Figure 9). This demonstrates that there is very little time lag as water infiltrates through 11 feet of sand at Well 49. In contrast, water level responses in Well 23 lag behind Well 49's response, usually by 1 to 2 months. This is the time it takes infiltrated recharge to travel the extra 110 feet to the water table at Well 23. Notice also that the water level plot for Well 23 is much smoother than that in Well 49, indicative of mixing of the infiltrating water as it travels that extra distance. The water level in Well 49 responds to individual rainfall events (Figure 4), while that in Well 23 does not.

2. Regional groundwater level changes in Richfield

As seen in Figures 3 and 4, groundwater levels do change through time. The monitoring program allows us to compare those historical changes seeking to identify anomalous responses. In particular, we should watch for areas or individual wells where water levels are declining. This could be an indication that there is undesired impact occurring from nearby pumping. Such locations warrant closer examination.

A first step in the analysis of the historical water level records was to subdivide the wells into geographic categories. Initially 5 areas were selected arbitrarily: northeast (NE), northwest (NW), southwest (SW), southeast (SE) and central (C). In the first 3 areas, most wells responded as if they were in an unconfined aquifer; water levels rose shortly after the spring recharge, peaked in May and June, and then dropped during the remainder of the year. These 3 areas can be seen in Figure 5.

Within the SW and C zones, however, there were 2 distinct patterns of water level response observed which were independent of geography. About half the wells responded to the spring recharge as if they were in an unconfined aquifer. Those have been identified on Figure 5 as lying within a zone called Unconfined. The remainder of the wells responded much differently, often not showing a recharge rise until late summer or fall, and then declining through winter and spring. This delayed response indicates that these wells are in a part of the shallow aquifer where the connection to the ground surface is much more complex. There is probably considerable clay in the geologic materials between the well bottom and the surface, forcing infiltrating water to travel longer distances to get around the clay. These wells are designated on Figure 5 as being in a Semi-confined aquifer; partially confined because of the very slow response, but not fully confined because water from the surface does reach them.

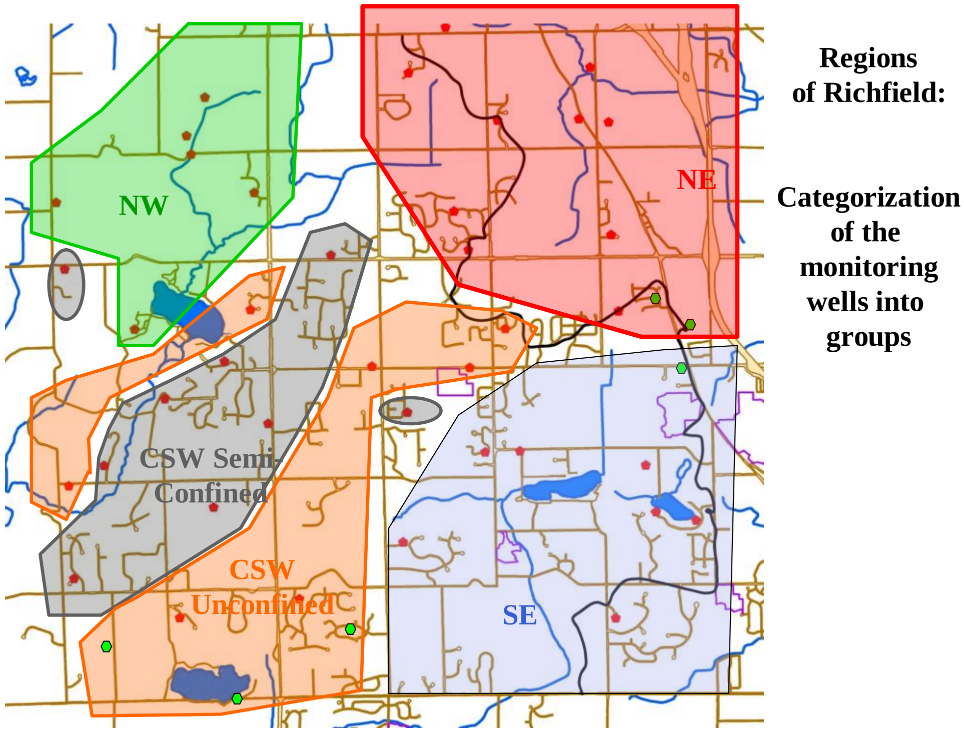

Figure 5 Subdivision of Monitored Wells into Five Categories The well array consists of 6 wells in the northwest (NW) region; 12 in the northeast (NE); and 8 in the southeast (SE) geographic regions. Wells in the southwest and central parts of the Village are grouped according to their hydrologic response. There are 10 in areas where the shallow aquifer is unconfined (CSW-unconfined) and 8 where the shallow aquifer responds as if semi-confined (CSW-semiconfined). Wells are the red and green dots.

Figure 6 plots the average change in groundwater level in each of the 5 regions in Richfield through the entire length of the monitoring program. The average elevation within each region in March, 2004, was arbitrarily identified as the baseline (0 relative elevation). If the line for a particular region plots above 0, then the average water level has risen relative to the start of the monitoring program. Conversely, if a line plots below 0, then the average water elevation has decreased.

Several important patterns emerge in Figure 6. For the first 4+ years of monitoring, all 5 regions showed very similar patterns; they went down in the drier years of 2005 and 2006, and then rose through 2007 into 2008. In 2008, Richfield's recharge and subsequent water levels were the highest observed during our monitoring program to date. Levels in all regions rose notably (Figure 6), but after the summer of 2008 the five regions responded differently to this large influx of water.

In SE and NW Richfield, water levels dropped much more quickly than in the other areas, and they have remained relatively lower. In the CSW area, groundwater levels stayed high for 3 to 5 years after 2008. The wells in the unconfined aquifer area fell back toward the other regions after about 3 years (Figure 6), while those in the semi-confined aquifer remained high for 5 years. The water levels in the semi-confined aquifer also lagged behind those in their neighboring unconfined wells (crests in semi-confined level typically were 1 or 2 measuring periods behind those in the unconfined). The wells in the NE area generally tracked in the middle of Figure 6.

Last year (2013) was another very wet one. As can be seen on Figure 6, water levels for all 5 Richfield regions rose, and more importantly the levels in all the regions converged back to where they are only about 3 feet apart. At this time, we don't know why.

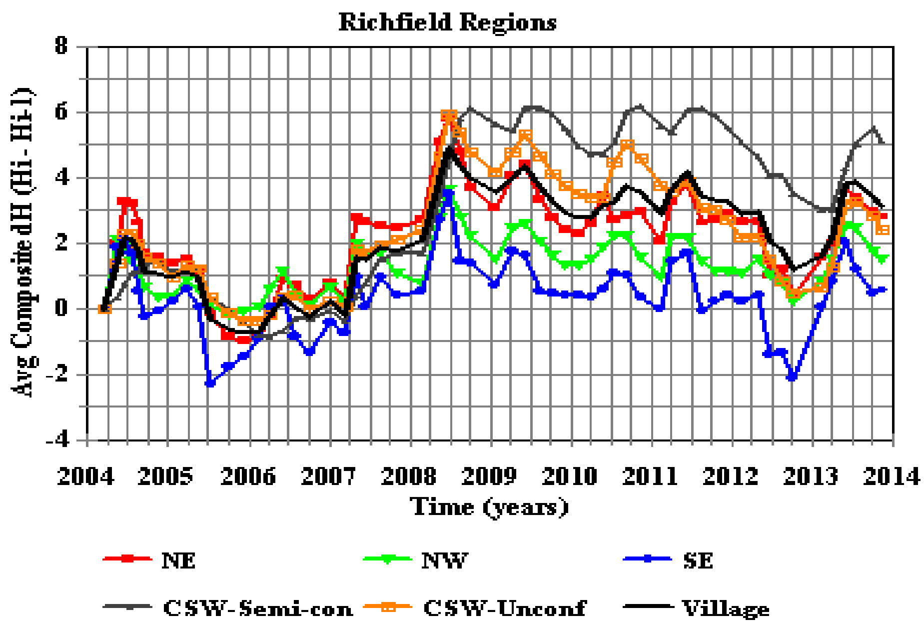

Figure 6 Changes in average groundwater elevation during the monitoring period for the regions shown in Figure 5.
Each point plotted is the average change in elevation from March, 2004, for a given region. Points plotting above 0 show a net water level rise; those below 0 show a net decline since March, 2004. The black line without markers shows the average for all wells in the monitoring array.
The rise in average water level from 2004 to 2013 for each region has been: NE +3.0 ft; NW +1.0 ft; SE + 0.7 ft;
CSW Unconfined +3.8 ft, and CSW Semi-confined +4.9 ft.

It's very important to note that all the regions ended 2013 with average groundwater levels higher than they were in 2004 (figure 6). In addition, almost all of the regional averages plot above 0 on Figure 6 for most of the monitoring period. This tells us that over the last 10 years Richfield's groundwater levels have risen. The rise has been an average of from 0.7 to 4.9 feet for individual regions and an average of about 3 feet for the Village as a whole. In addition, all but 3 of the individual wells monitored since 2005 had higher water levels in 2013 than 2005. During the monitoring period, the quantity of Richfield's groundwater supply has remained very strong.

Presenting the results for the Richfield areas in different ways may make trends somewhat easier to see. In Figure 7, the changes in water level shown in Figure 6 are accumulated through time so that you can see the overall trend. This shows that all regions have seen water level increases during the monitoring period, but that the SE and NW area increases have been smaller than elsewhere.

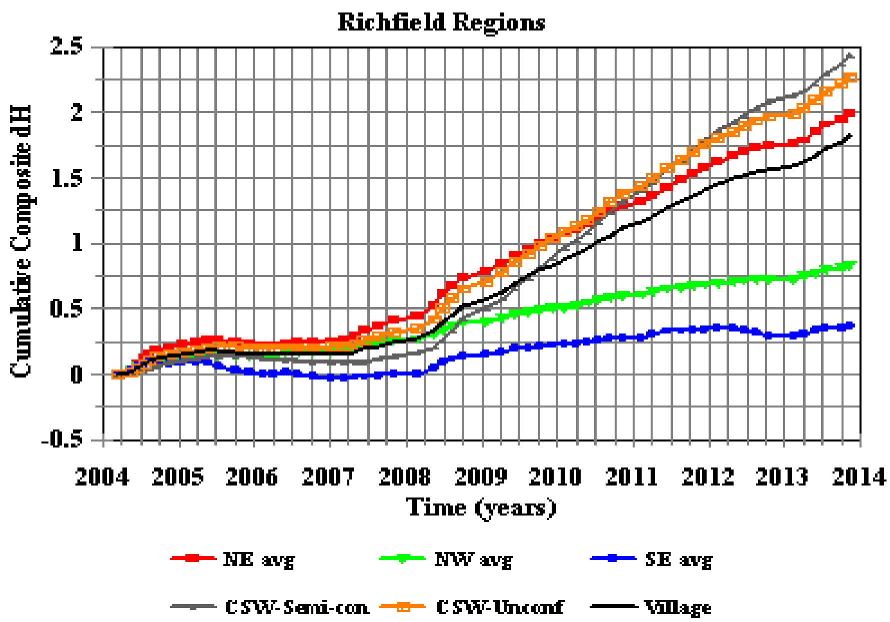

Figure 7 Accumulated change in water elevation through time. All regions within Richfield have shown a net increase (upward trend on the line) during the 10 year monitoring period. Only the SE area ever dropped below 0 to indicate a net decline in water level from 2006 to 2008. The Village average is the black line.

Figure 8 shows how each region has responded relative to the Village average water level. In it, the difference between a region's average and the Village average in Figure 7 has been plotted through time. If a region has increased more than the Village average, it plots above 0 on Figure 8. If it plots below 0, then its water level has not increased as much as the Village as a whole. It becomes clear that water levels in the SE and NW regions have not risen as much as those in the rest of the Village.

Figure 8 also shows that this pattern actually has been going on the entire monitoring period (blue and green lines plot the lowest in Figure 8). Initially the NE (red line) plotted the highest. Once again, in 2008 the patterns changed dramatically. The CSW regions increased much faster, while the SE and NW began to drop off and the NE region leveled off. The cause of this change in pattern remains unknown at this time.

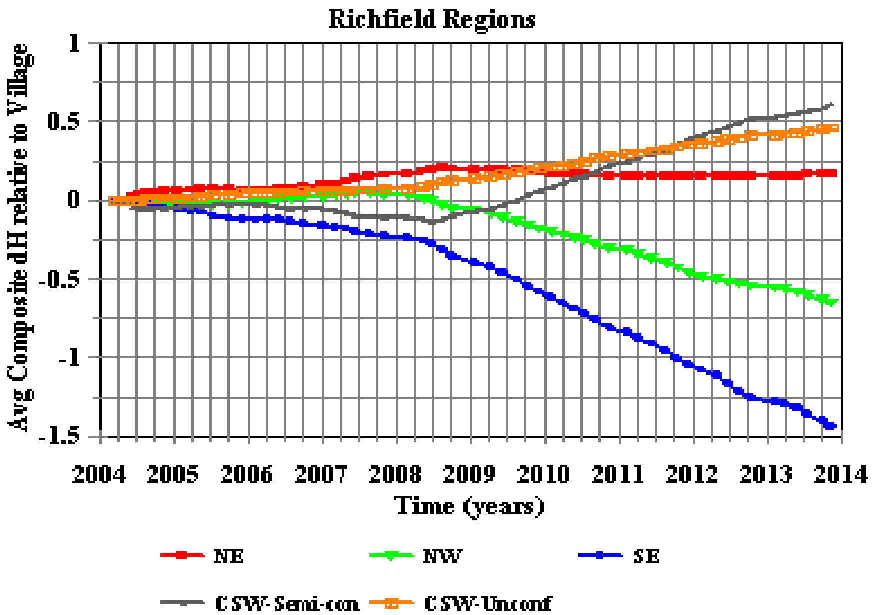

Figure 8 Change in average water level through time relative to Village average. A downward trend shows a region's water level is not increasing as much as the Village as a whole. An upward trend indicates the opposite.

Examination of potential areas of concern

One of the primary purposes of the Richfield monitoring program is to allow us to watch for areas where groundwater levels have been impacted by heavy water use or land use practices that alter the natural hydrological system.. Typically such impacts would cause water levels to decline, although there could be instances where human activity raises the water table. An example of the latter might be redirecting surface runoff to infiltration ponds or blocking off a natural drainage way when constructing a new road. Either could cause the water table nearby to rise, in some instances even above the ground surface.

To date, we have not encountered any situations in Richfield where human activity has caused notable groundwater level rises, so this article will focus on level declines. Locations where large quantities of groundwater are pumped, such as quarries or sand/gravel operations, golf courses, or dense residential development warrant attention. Commercial operations such as tree nurseries, food processing, laundering, car washes or health care facilities could also negatively impact groundwater levels, but at present none of these exist in Richfield.

Currently, there are a few locations in Richfield which should be examined to see if they are having a detrimental effect on neighboring wells. They include:

1. The active sand and gravel operation just north of Pioneer Road and west of Scenic Road,
2. The golf courses along Holy Hill Road,
3. The recreational complex at Holy Hill and Highway 175, and
4. The high density residential development currently underway southeast of the intersection of Holy Hill and Highway 175.

The existing monitoring array (shown in Figure 9) is generally adequate to allow identification of negative impacts at these locations. We have added wells 2, 12 and 60 (Figure 9) to the array in recent years to give better coverage along Highway 175.

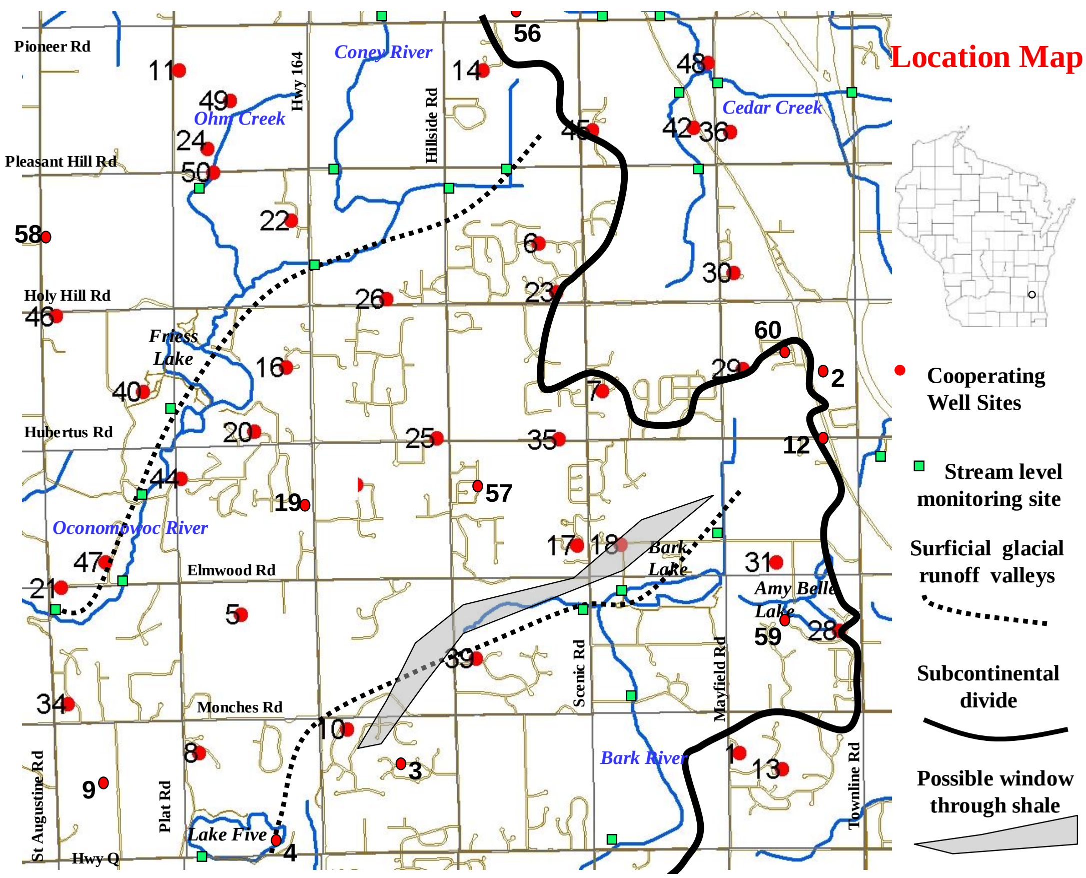

Figure 9 Location of Monitoring Sites
The wells are identified here with their numerical designation to allow correlation with subsequent figures. The glacial runoff valleys are explained in the article on Richfield's hydrogeology on this website.

In addition, groundwater levels in monitored wells in the southeast portion of Richfield have consistently shown lower increases during wet years and greater decreases during dry years than wells in other parts of the Village. This phenomenon should also be investigated.

Plots for individual wells similar to Figure 8 are the simplest way to look for negative impacts near pumping centers. If the cumulated change in water level through time relative to the Village average plots strongly downward, it could be indicating that water level in the monitored well may be impacted. Figure 10 provides those plots for all the monitored wells near known pumping centers.

Well 23 (my well) is included on Figure 10 to serve as a control location. My well is relatively close to all these pumping centers, but far enough from them to not be effected by them. The water level in Well 23 has tracked very close to the Village average (horizontal plot on Figure 10) over time.

1. Active sand/gravel extraction site northwest of Pioneer and Scenic

Groundwater is being pumped from a high capacity well along Scenic Road north of Pioneer Road at an average rate of 24,000 gallons per day (gpd). The water is used to wash silt and clay from the sand and gravel. After the washing process, the used water is discharged to infiltration ponds where much of it returns to the shallow aquifer. Wissota Sand and Gravel has allowed us to monitor 2 of their wells: number 56, which is at the site of a former house on Pioneer Road, and number 54, which is at the company's local office on Scenic Road. Well 54 is about 0.25 miles north of the high capacity well, while Well 56 is about 0.5 miles southwest. The infiltration ponds lie between the high-capacity well and Well 56.

As can be seen in Figure 10, the well closest to Richfield (Well 56) has not shown any significant downward trend in relative water level, while Well 54 does. This indicates that the quarrying operation may have an impact on groundwater levels, but that impact is occurring only to the north of the quarry. The return of the wash water through the infiltration ponds eliminates groundwater level impacts to the south. In fact, the nearest well in Richfield (Well 14 on Figure 9, but not shown on Figure 10) actually shows a modest water level increase relative to the Village average. In short, the sand/gravel operation is not impacting Richfield's groundwater level.

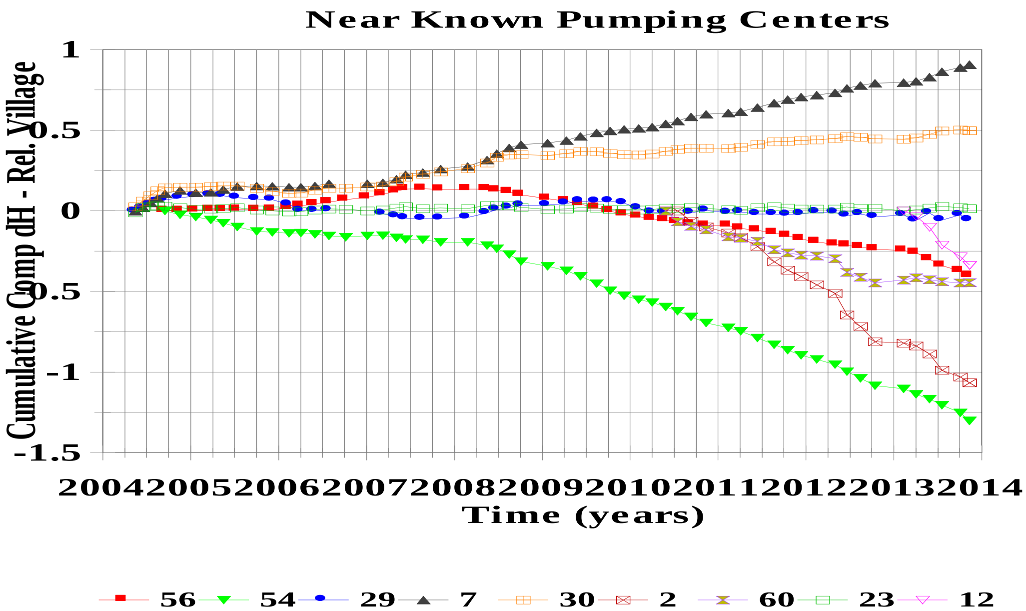

Figure 10 Change in groundwater level in wells near pumping centers relative to Village average
Wells 54 and 56 are near an active sand/gravel extraction site north of Pioneer Road and west of Scenic Road. Wells 29 and 7 are near the golf courses along Holy Hill Road. Well 30 is closest to the baseball fields at Holy Hill and Highway 175. Wells 2 and 60 are near the residential development along Highway 175 and south of Holy Hill. Well 23 serves as a control site, over 3/4 mile from any known pumping center.

2. Golf courses along Holy Hill Road

Kettle Hills golf course pumps an average of 180,000 gpd during the months of May through September from a high-capacity well just south of Holy Hill Road. The well is 92 feet deep and taps the sand and gravel aquifer. Water is pumped into a pond which is used to irrigate the golf course. During the remainder of the year, when the course is closed, there is no water pumped from this well. Arrowhead Springs golf course does not have a high-capacity well, so no pumping data are available on the WI DNR website.

Well 29 is almost entirely surrounded by the Kettle Hills courses Figure 9), while Well 7 lies about 0.5 miles southwest of the pumping well. The former well has tracked parallel to the Village average over time, while the latter has actually had its water level increase slightly relative to Richfield's average (Figure 10). Based on our monitoring wells, it appears that the golf course operations are not producing any widespread negative impact on groundwater levels.

3. Recreational complex at Holy Hill and Highway 175

Pioneer Bowl and Logger's Park both irrigate their ball fields during the summer months. Neither uses a high-capacity well to do so, meaning that their pumping rates are not on the WI DNR website. However, Well 30 is located less than 0.5 miles (Figure 9) from the ball fields. Over time, the water level in Well 30 has risen slightly relative to the Village average (Figure 10), so the recreational complex is not adversely effecting its groundwater level.

4. High density residential development underway south of Holy Hill and east of Highway 175

As part of its long-term planning, Richfield identified areas east of Highway 175, both north and south of Holy Hill Road, for development as "walkable hamlets". The housing would be on smaller lots (denser) than elsewhere in the Village, but the areas would continue to rely on groundwater for their supply and would return their wastewater to the ground via onsite septic systems.

Reflections Village is already under development south of Holy Hill Road. Homes and businesses there are being served by private, but communal, wells and wastewater systems. These water systems provide service only within the development; they are NOT municipal water systems. The high-capacity well is classified by the WI DNR as an "other than municipal" (OTM) private water well. It is 363 feet deep and is completed in the dolomite.

At this time, there are fewer than a dozen occupied homes and one bank on the site. From June, 2012 through June, 2013, an average of about 3800 gpd was pumped from the development's well. In the very dry summer of 2012, water from the well was used to replenish the development's stormwater ponds so that they could be used as a water supply by the Richfield Fire Department. Pumping during that summer averaged almost 13,000 gpd. Subsequently, much less water has been pumped, because of very wet conditions in 2013. Post July, 2012, pumping has averaged only 2800 gpd.

At full buildout, the development's anticipated water demand is nearly 58,000 gpd. If this amount of water were to be pumped from the shallow aquifer alone, the development could not achieve compliance with Richfield's Groundwater Protection Ordinance. Consequently, the Village has issued a groundwater protection permit that requires Reflections Village to install a well into the deep sandstone aquifer to supply at least half of that ultimate demand. The deeper aquifer is not used by other wells in Richfield, so any drawdowns that would occur there would not affect Richfield residents.

The record of wells near the Reflections site differs from that seen for the wells at other pumping centers. Well 2 is an observation well drilled for the Village on the Reflections site, as a condition for approval of the first phase of the project. It is about 0.25 miles from the pumping well and only 100 feet from the property's western boundary. Well 60 is a residential well about 0.5 miles to the west. Both wells show declining water levels relative to the Village average (Figure 10), although the relative decline in Well 60 is much smaller. Both of these wells are completed in the dolomite portion of the shallow aquifer.

Well 12 is about 0.5 miles south of the Reflections well. It was added to the monitoring array in late 2012, so it has a very short record on Figure 10. However, the early results show a rapid decline relative to the Village average. It is showing a more rapid decline in water level relative to the Village than even Well 2. Because Well 12 is some distance away from the Reflections Village pumping well, its response is probably due to pumping wells south of Reflections. A search of the WI DNR website has not yet found pumping rates for such wells, however.

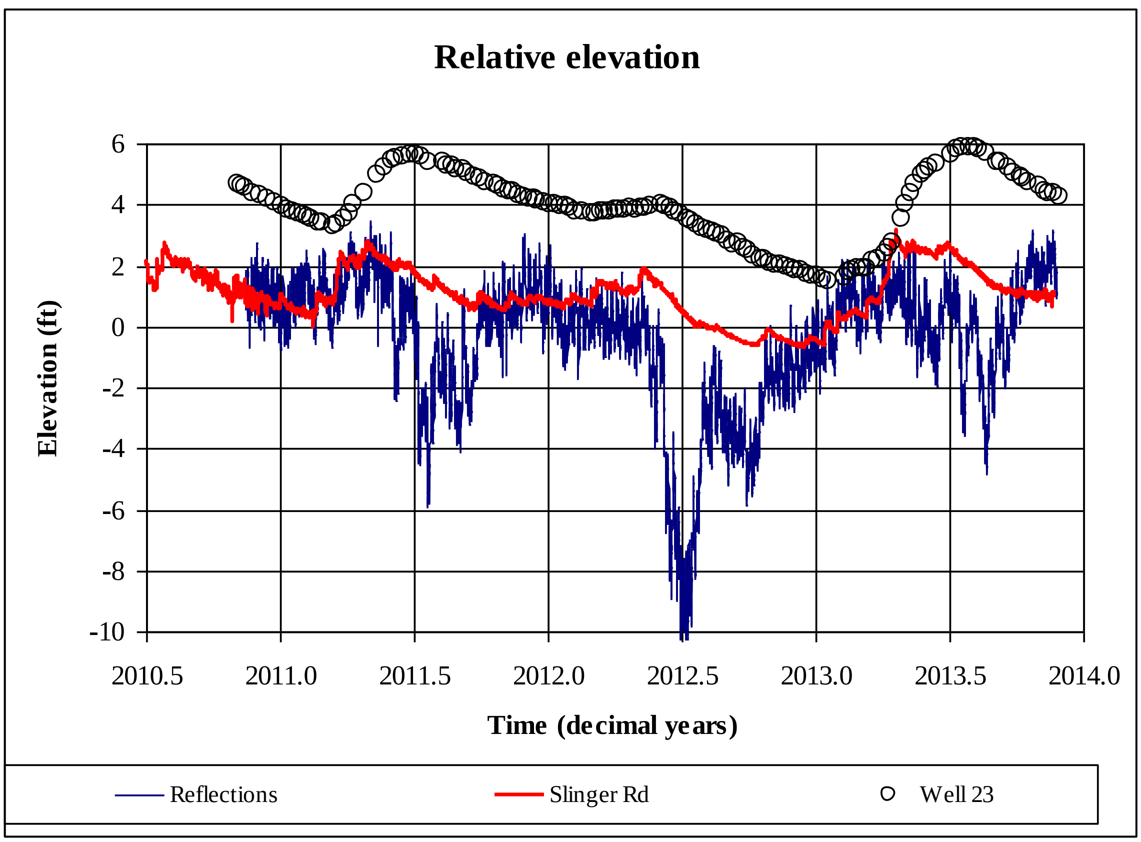

Figure 11 Comparison of the water level in the Reflections observation well with other frequently monitored sites. "Slinger Rd." is Well 49, Well 23 is the author's, and "Reflections" is Well 2 in Figure 9. In addition to the seasonal level changes which the other 2 wells exhibit, the Reflections well shows a pronounced drop in water level during the summer months (from 2012.4 to 2012.8, for example).

A transducer has been measuring water level every 2 hours in the Reflections well since June, 2011. With the exception of summertime, the water level pattern is remarkably similar to that in Well 49 (Slinger Rd.), despite major differences between the 2 wells. They are nearly 6 miles apart (Figure 9). Well 2 (Reflections) is 300 feet deep, and is in the dolomite with an average depth to water of over 130 feet. In contrast, Well 49 is only drilled 30 feet into the sand and gravel and has an average depth to water of about 11 feet.

In the summer, the water level in Well 2 drops notably and rapidly, while that in Well 49 continues its seasonally decline. Toward the end of September, the water level in Well 2 rises back to roughly that in Well 49. This is indicative of heavy local pumping in or around Well 2, and the distance between the water level lines of the 2 wells on Figure 11 is a rough estimate of how much the dolomite's local water level is drawn down.

Based on what is known about the hydrogeology around the Reflections site, the Reflections pumping well is probably not the sole cause of the summer drawdowns observed in Well 2. Even the large pumping rates of summer, 2012, cannot fully explain the 8 feet of drawdown that seems to be shown on Figure 11. It could be that there are other large, and as yet unidentified, pumping wells near the Reflections site, but examination of the WI DNR records for high-capacity wells hasn't revealed any that should be active only in the summer.

Further examination of water levels in southeastern Richfield

Recall that the water levels in SE Richfield have historically been rising less than those in the rest of the Village. This suggests that the cause of some portion of the relative decline near Reflections Village may be broader in scope than just a simple pumping well or two.

Although it can't be proven at the present time, the evidence we have from our monitoring program points to a geologic cause for part of the relative declines in water level on the east side of Richfield. Back on Figure 3 a small gray area was labeled "possible window", adjacent to a location northwest of Bark Lake where the monitored water level is always lower than any nearby well.

It appears that the Maquoketa Shale, which is the barrier (aquitard) that separates Richfield's shallow aquifer from the regional deep sandstone aquifer, has been breached somewhere under SE Richfield. This would have occurred when massive rivers of glacial meltwater carved deep valleys into the bedrock as the Ice Age glaciers melted. The deepest penetration would have been near the surficial glacial runoff valleys shown on Figure 10. If runoff cut through the Maquoketa, that would form an opening ("window") through which water could travel between the 2 regional aquifers. Because of heavy regional pumping, the water level in the sandstone aquifer is lower than that in the shallow system, so the flow would be downward, draining some water from Richfield's shallow system. This could explain why levels in SE Richfield have not risen as much as in other parts of the Village during the monitoring period.

Figure 12 shows the cumulative relative change in water level through time for all the wells near the hypothesized window. Note how most of the plotted wells show a relative decline through time which is similar to those seen for the entire SE part of Richfield (Figure 8) and for Wells 2, 12 and 60 from Reflections Village south (Figure 10). Drainage through the window could potentially affect wells across a broad part of the Village, not just those lying directly above it. This would explain why there are so many wells with a similar relative decline in Figure 11. It could also explain some portion of the unexpectedly large summer declines under Reflections Village.

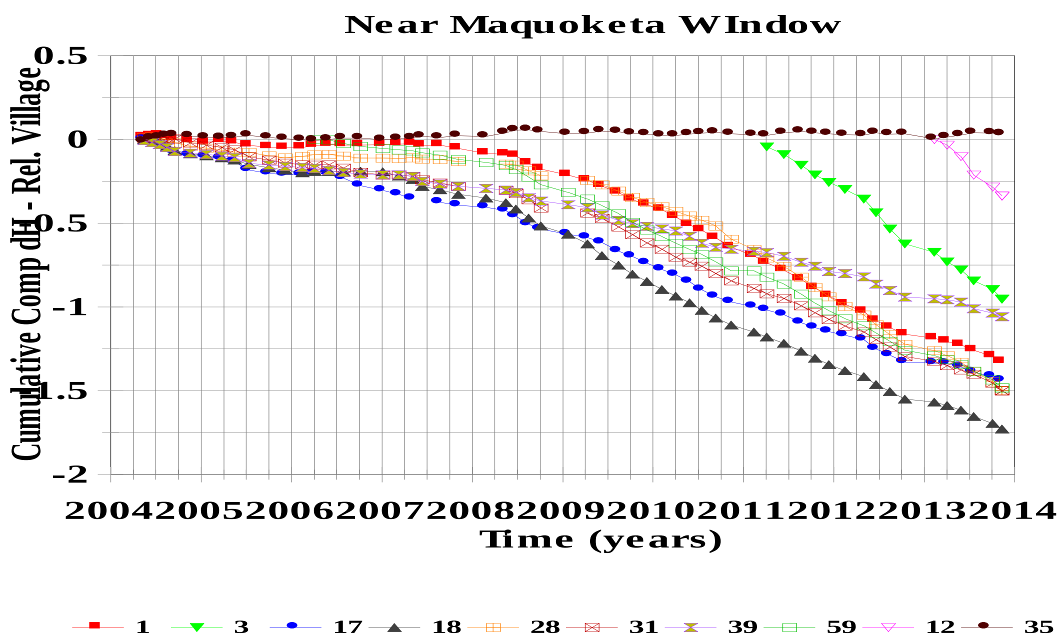

Figure 12 Change in groundwater level relative to Village average in wells near the hypothesized window through the Maquoketa Shale Well locations are shown in Figure 9. Well 35 serves as a control well; it is not near the suspected window.

At this time, the answer to the dilemma of the water levels in southeastern Richfield is not clear. The monitoring periods of the wells around Reflections Village are relatively short. Further monitoring should allow a better answer in the future.

Conclusions and Recommendations

Conclusions

Richfield is totally dependent upon groundwater as its source of water supply. Beginning in late 2003, we began a program to monitor groundwater levels throughout the community. Those measurements have allowed us to identify the basic groundwater flow pattern within the Village. We have learned that rainfall and snowmelt within Richfield is the source of most of our water supply, meaning that we can readily protect that resource if we choose to.

As a community, we have developed a three part program to accomplish that protection. We have established a land-use plan that protects groundwater recharge and minimizes water demands. We've coupled that with expansion and continuation of the program to monitor water levels, and we have created and enforce a groundwater protection ordinance designed to assure residents that their wells will not be unacceptably drawn down by new development. This Richfield Groundwater Protection Program is unique within our state, forward-thinking, and it is working.

Through ten years of monitoring, we have learned that:

1. Our groundwater supply, as interpreted from water levels in 43 wells, has actually increased since 2004. Water levels are up an average of three (3) feet, partly due to 2013 being a very wet year.

2. Water levels in all parts of the Village have risen, although not uniformly. Levels are up the most in the southwestern part of the Village and the least in the southeast.

3. Biannual testing of the wells for coliform bacteria shows there is no persistent or widespread contamination. A few of the tested homes tested positive, but the bacteria generally entered the water after it left the well; there were no bacteria in the tested wells in 2012.

4. These first three points demonstrate there is no need for municipal water or sewer in Richfield, the same argument that was made during the hearings for Richfield's application to incorporate as a village. Our water supply is stable or increasing, and there is no discernible bacterial contamination.

5. Residential developments approved after 2004 were all able to show that their future drawdowns of the water table will be less than one (1) foot at their boundaries. This means that low to medium density residential development can be done while also protecting the groundwater resource.

6. To date, there is no evidence that the existing commercial and recreational entities who are heavy water users are having an adverse impact on nearby monitored wells.

7. The groundwater system of the east and southeast portions of Richfield requires further analysis. Water levels in this area have shown the smallest increase in the Village. Much of the area has only the dolomite aquifer to draw from and also has a number of competing groundwater users. The groundwater here is apparently impacted by:

   a. The relatively recent additional (and growing) pumping at Reflections Village,
   b. Pumping from other, as yet unidentified, large wells, and
   c. Possible leakage to the deep sandstone aquifer.

<u>Recommendations</u>

Richfield should continue to conduct and enforce all aspects of its Groundwater Protection Plan. It needs to:

1. Adhere to the long-range land use plan as closely as possible,
2. Continue the monitoring of water levels, with some enlargement of the array,
3. Enforce the existing Groundwater Protection Ordinance

In addition, the Village should consider enhancing the plan by:

1. Extending the provisions of the Ordinance to include examining the impacts of major changes in water demand in developments, and
2. Including the measurement of some basic water quality parameters in the monitoring program so that we can establish a water quality baseline similar to the water level data set we have now.