Groundwater Research Report
WR13R002

GROUNDWATER-SURFACE WATER INTERACTIONS CAUSED BY PUMPING FROM A RIVERBANK INDUCEMENT WELL FIELD

Timothy Grundl
Laura Fields-Sommers
Jack Graham

Funding Year:
2013

Groundwater-Surface Water Interactions Caused by Pumping from a Riverbank Inducement Well Field

Tim Grundl[1,2], Laura Fields-Sommers[2], Jack Graham[1]

[1]Geosciences Department and [2]School of Freshwater Sciences,

UW-Milwaukee

Final Report submitted to Wisconsin Groundwater Research Program at completion of grant number WR13R002

Table of Contents

List of Figures and Tables

Figures

Tables

PROJECT SUMMARY

Title: Groundwater-Surface Water Interactions Caused by Pumping from a Riverbank Inducement Wellfield

Project ID: WR13R002

Investigator(s): Tim Grundl, Professor, Geosciences Department UW-Milwaukee
Laura Fields-Sommers, Research Assistant, Geosciences Dept. UW-Milwaukee

Period of Contract: July 1, 2013-June 30, 2015

Background/Need: In parts of southeastern Wisconsin treated municipal wastewater effluent is entering the shallow aquifer via inducement of effluent-containing river water into the shallow aquifer. Because the surface sediments in southeastern Wisconsin are often glacial in origin with highly variable hydraulic properties the efficacy of using riverbank inducement (RBI) as a water source is not obvious.

Objectives: The overall goal of this research was to develop a set of tools that can be used to evaluate the effect of riverbank inducement wells on local groundwaters.

Methods: An existing RBI well field consisting of 2 riparian wells and a pristine groundwater well located in an urbanized stretch of the lower Fox River (Waukesha County) was used as the study site. All three wells are part of a municipal water supply system. A large proportion of Fox River flow at this site consists of treated municipal wastewater. This is an ideal site because it has been the subject of several previous studies and much is already known about the local hydrology and geochemistry.

Results/Discussion: Fox River water is clearly entering the two RBI wells. The pristine well is hydrologically separate from the river and does not pump river water. Estimates obtained from major ion composition and B/Cl ratios indicate that the RBI wells produce up to 59% river water. This maximum was reached in late 2013 and has declined since. B/Cl ratios indicate that the source of sodium chloride in the Fox River, and therefore in the RBI wells, is dominantly wastewater treatment plant (WWTP) effluent originating from the three upstream WWTPs. The effect of road salt on the river itself and on the RBI wells is minimal. 97%-95% of the annual sodium chloride load carried by the Fox river originates from WWTP effluent with the balance coming from road salt contributed during the annual spring melt. Five pharmaceuticals and personal care products (PPCPs) were found in WWTP effluent and the Fox River adjacent to the wellfield. Of these, only sucralose was detected in the RBI wells. Sucralose is the most mobile of the PPCP contaminants found in the Fox River. More highly retarded PPCPs will likely begin appearing in the RBI wells in the future. qPCR data was collected and analyzed for the presence of fecal bacteria in the wellfield. Although both generic and human-specific fecal bacteria were found in the Fox River, no fecal bacteria was found in any well.

Conclusions: The use of various geochemical tracers, in combination with numeric flow modelling (from another study) were used to demonstrate that RBI is occurring in these wells – a fact that is not obvious in an area with complex glacially deposited sediments. WWTP effluent, not road salt, is clearly the source of the elevated sodium chloride in the Fox River, and therefore in the RBI wells. This raises the possibility that more dangerous constituents may eventually enter the wellfield. So far, only sucralose has been detected in the wellfield although less mobile constituents will likely appear in the future. To date, no indication has been seen of fecal bacteria transport from the Fox River to the wellfield. Continued monitoring of this wellfield is the only way to see if these trends continue in the future.

Related Publications: Fields-Sommers, L. (2015) Assessing the Effects of Riverbank Inducement on a Shallow Aquifer in Southeastern Wisconsin, Masters Thesis School of Freshwater Sciences, UW – Milwaukee, 211 pp.

Key Words: riverbank inducement, geochemical tracers, wastewater effluent
Funding: UW System funds

INTRODUCTION

Southeast Wisconsin and the Milwaukee metropolitan area in particular is growing rapidly which is causing increasing demand on local aquifers to supply drinking water. Currently people in SE Wisconsin use a total of approximately 45 million gallons per day (mgd) of groundwater from the shallow aquifer for their drinking water supply with expected population growth calling for an additional of pumpage every year ((SEWRPC, 2010). One reason for the regional trend towards utilization of the shallow aquifer is the rapid rate of recharge in comparison to the deep aquifer and the direct interconnection with local surface water. This allows for the possibility of recycling municipal water either implicitly by siting shallow wells near surface water bodies that accept treated effluent (the current practice) or explicitly through artificial recharge of treated effluent. The placement of water supply wells near large rivers in order to induce river water to flow to the wells is called river bank inducement (RBI). In many areas of Wisconsin the surface sediments are glacial deposits with highly variable hydraulic properties and the efficacy of using RBI as a water source is not obvious. In addition, the close interaction between surface water and groundwater means that the shallow aquifer is vulnerable to contamination and there is worry that direct inducement of river water into groundwater systems will lead to future contamination. The interplay between rivers and the underlying groundwater is complex due to temporal variability in river stage and river chemistry as well as spatial variability in the hydraulic properties of riparian deposits and there is the resultant need to develop tools that will allow for a clear understanding of RBI in shallow aquifer systems. When a well is constructed in the shallow aquifer near a river, the water it pumps is a mixture of two sources: a) the water it induces directly from the riverbed and b) native ground water, some of which would have flowed to the river as baseflow in the well's absence. The pumped water starts with the quality of native groundwater, but then is altered as induced river water begins to enter the well. The overall goal of this proposed research was to develop a set of tools that can be used to evaluate the effect of riverbank inducement wells on local groundwaters.

An existing RBI well field located in the riparian zone of an urbanized stretch of the Fox River (Waukesha County) was used as the study site. A large proportion of Fox River flow at this site consists of treated municipal wastewater. The most notable anthropogenic effect on ground and surface waters in urbanized areas is a rise in chloride concentrations (Klump et al. (2008); McIntosh et al. (2011) and the references therein). Chloride is used in a wide variety of industrial processes, deicing applications, agriculture, food and metal processing and in water softeners. The effect on surface waters is quite pronounced. Shallow groundwater is the repository for some of this large chloride loading and many studies have found elevated levels of chloride in shallow groundwater (McIntosh et al., 2011).

Although application of road salt is the major contributor to chloride loading in metropolitan areas and is certainly the cause behind large seasonal spikes in chloride concentrations, treated effluent from municipal waste water treatment plants (WWTP) is also a major additional source. Loading from WWTP effluent is much more evenly distributed throughout the year and comprises a large percentage of the total amount of chloride entering the groundwater in urban areas (eg. Beyerle et al. (2000); Holzbauer (2010)). The apportionment of chloride into that which originates in a WWTP and that originating from road salting has been attempted using a variety of geochemical tracers. The most commonly used tracers are Cl/Br ratios, boron and boron isotopes, lithium and lithium isotopes, and gadolinium (Balkwill and Ghiorse (1985); Beyerle et al. (2000); Chapelle (1992); Holzbauer (2010); Lisle (2014); White et al. (1983)). Boron, lithium and gadolinium are found in higher concentrations in treated effluent than in water contaminated with road salt because laundry whiteners, depression medication and medical imaging respectively add additional amounts of these three elements to treated effluent. Other useful discriminants of WWTP effluent include the stable isotopes of water and a variety of pharmaceuticals and personal care products (PPCP) that are widely found in the environment. Artificial sweeteners, in particular acesulfame and sucralose, are among the most stable PPCP compounds and are useful as effluent tracers in groundwater (Buerge and Poiger (2011); Kahle et al. (2009); Wolf et al. (2012)).

PROCEDURES AND METHODS

The sampling network used in this study is a subset of a larger sampling network that has been maintained for 10 years. The overall network consists of eighteen sampling sites: seven high capacity wells, seven river locations, one artesian spring and three Waste Water Treatment Plants (WWTPs). The sites are located in the Root, Menomonee, and Upper Fox River watersheds of Waukesha and Milwaukee Counties, Wisconsin. Ancillary sites include an artesian well, three river sites, and a mixture of four dolomite and standing gravel aquifer wells (Figure 1). The main sites used in the current study are the three WWTPs, Fox River site 2, the RBI wellfield (wells RL255, RL256, WK947) and the Isco sampling site. Latitude/longitude coordinates and owner contact information for all sites can be found in Appendix B.

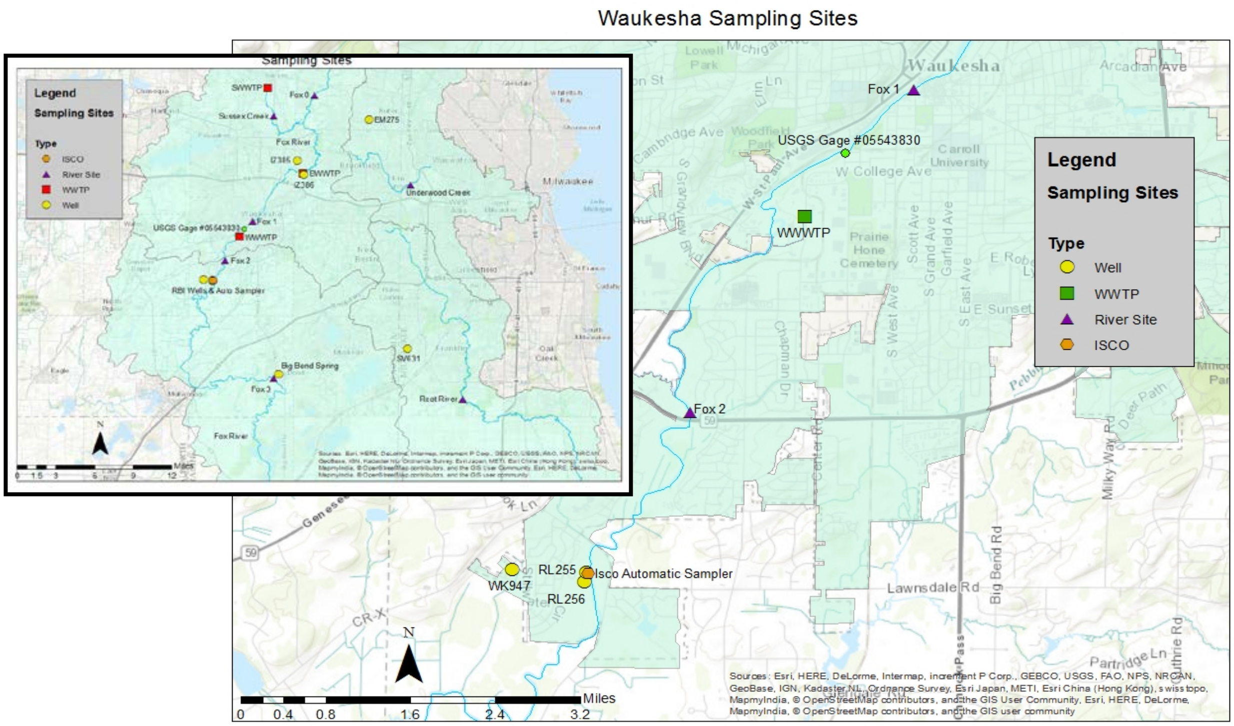

Figure 1. Map of the primary sampling sites, with light green indicating urban land use. Inset map shows the overall sampling network. Wells are denoted by WDNR unique well ID number. The Sussex, Brookfield and Waukesha wastewater treatment plants are denoted SWWTP, BWWTP and WWWTP respectively.

The RBI wells are maintained by the Waukesha Water Utility and are screened in a shallow sand and gravel aquifer consisting of glacial and alluvial materials of the New Berlin Member of southeastern Wisconsin. RL255 is located 69 m (225 ft) from the river and is screened from a depth of 27 to 38 m (90 to 125ft). RL256 is located 25 m (83 ft) from the river and is screened from a depth of 19 to 44 m (62 to 143 ft). WK947 is screened in the same aquifer (at a depth of 25 to 32 m (83 to 105ft)) but is located 457 m (1,500 ft) from the riverbank. This well has no hydraulic connection to the Fox River and supplies water that is representative of pristine groundwater in the area. The Isco automatic sampler was positioned in the Fox River immediately adjacent to RL255. Well construction reports for all three wells can be found in Appendix B.

RESULTS and DISCUSSION

<u>Major ions in the RBI wellfield</u>

The major ion chemistry observed in WK947 remained constant over the entire time that it has been pumped. This well is hydraulically distinct from the river and as such is pumping pristine groundwater. The invariant trends in cation concentrations in WK947 are shown in Figure 2.

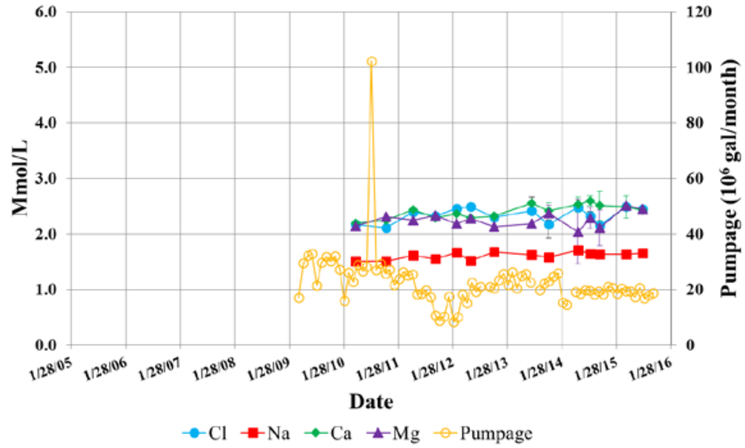

Figure 2. Major ion chemistry in WK947 from 2008 through 2015. Yellow line is the average monthly pumpage. Pumping in this well began April 2009. Error bars are ± 1 standard deviation.

Of particular interest is the constancy of chloride concentration at 2.34 ±0.14 mMol/L (83 ±5 mg/L) and sodium concentration at 1.61±0.07 mMol/L (37±2 mg/L). The only notable difference in major ion chemistry between the Fox River and pristine groundwater is the much higher sodium and chloride levels in the Fox River; 6.59 ±0.84 mMol/L (151±19 mg/L) and 7.57 ± 1.36mMol (269 ± 48 mg/L) respectively. Because of this stark difference sodium and chloride levels can be used as tracers for the presence of river water.

The groundwater chemistry in the two riparian wells (RL255 and RL256) show a slow continual rise of sodium and chloride levels from 2007 until the beginning of 2014. Thereafter both sodium and chloride concentrations began to show a gradual decline (Figure 3). This is especially apparent in well RL255. This pattern is the result of the varying pumping rates that have been impressed upon the well field since it opened in November of 2006. The effect of variable pumping rates on the amount of river water that is being induced into the riparian wells was investigated by using the Upper Fox River groundwater model (Feinstein et al., 2012). Although there is a continual drop in pumpage over time from all three wells (Figures 2, 3), the relative percentage of total well field water being pumped by each well falls neatly into three periods as is seen in Figure 4.

In the first period, before WK947 was installed, the pumpage was split 70:30 between wells RL 256 and RL255 respectively. The second period exhibited a 50:35:15 split between WK347:RL26:RL255 and in the third period a 60:30:10 split between WK347:RL26:RL255. The Upper Fox River model was run with three stress periods that correspond to the average pumpage in each of these percentage periods. As WK947 captures ever more pristine groundwater (from 0% to 50% to 60%), the two riparian wells will pump relatively more river water. This effect is counterbalanced in stress period three by the overall pumpage in the two riparian wells decreasing to the point that water is being replenished to the aquifer (negative storage release) and the percent of pumpage from the river declines. The modelling indicates a continual rise in induced streamflow over time reaching a maximum of 30% by late 2012 followed by a diminution of induced streamflow to approximately 10% if the current pumping regime remains in effect.

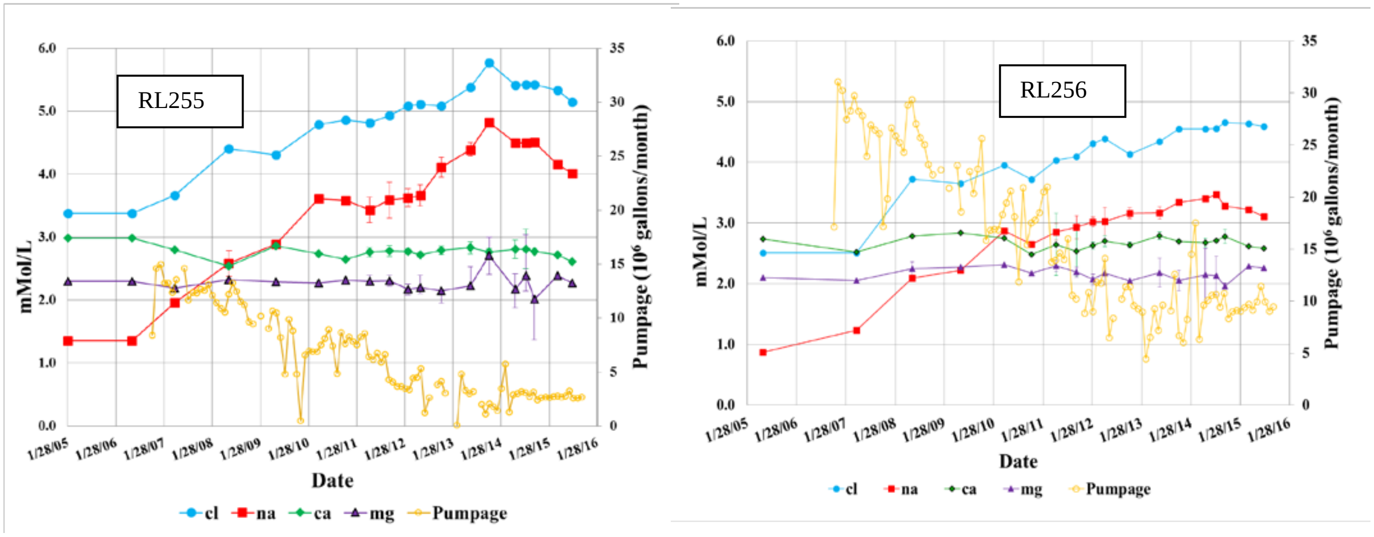

Figure 3. Major ion chemistry in the riparian wells RL255 and RL 256 from 2005 through 2015. Yellow line is the average monthly pumpage. Pumping in these wells began in November 2006. Error bars are ± 1 standard deviation.

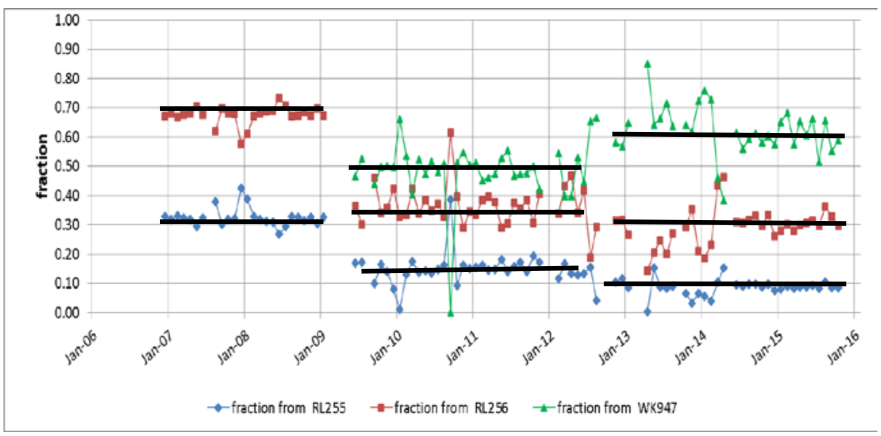

Figure 4. Pumpage history in the wellfield expressed as the fraction of total pumpage originating from each well. RL255 and RL26 are riparian wells, WK97 is unaffected by the river and produces pristine groundwater.

This general trend of an ever increasing percent of induced streamflow in the riparian wells followed by a decline also appears in the major ion chemistry of both riparian wells. As is most evident in RL255 (Figure 3), the rise in chloride and sodium concentrations over time levels off in 2014 and begins to decline in January 2015 indicating less induced streamflow. The decline in induced streamflow as seen in the chloride and sodium concentrations occurs approximately 1 year after the modelled decrease in induced streamflow. This one year lag time is consistent with a previous particle tracking study using the Upper Fox Rier groundwater model which reports average travel times from river to riparian wells of 0.7-0.9 years (RL25) and 1.0-2.5 years (RL 256) (Feinstein et al., 2012).

Chloride concentrations can be used to estimate the maximum percentage of induced streamflow in each well by assuming that the rise in chloride is entirely due to increasing contribution of river water. In RL255, the maximum chloride concentration was 5.8 mMol/L, the original concentration was 3.4 mMol/L and the average Fox River concentration was 7.9 ± 1.4 mMol/L. Using these concentrations, the maximum amount of induced streamflow was 59 ± 30% . The same calculation for RL 256 (using 2.5 mMol/L and 4.7 mMol/L for the original and maximum chloride concentations) yields a maximum induced streamflow of 39 ± 25%.

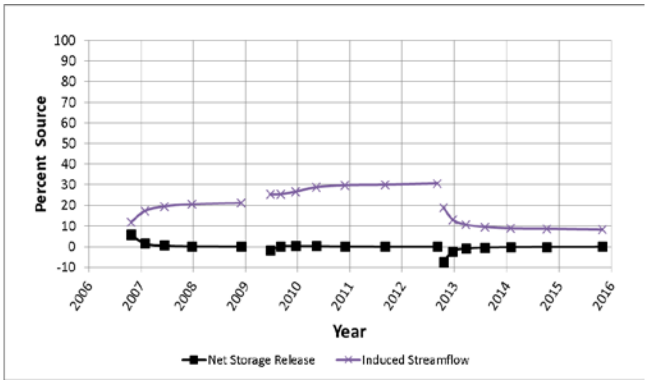

Figure 5. Results of numerical modelling of the Waukesha wellfield showing the percent induced streamflow and net storage release for each stress period. Stress periods correlate to the pumping history as seen in Figure 4.

Sodium chloride source discrimination

Although the presence of increasing amounts of chloride in the two riparian wells is indicative of river water being drawn into the wells, it is not clear from this data alone if the chloride load is due to road salting, to water softening salt or to the presence of saline WWTP effluent in the river. The ratio of boron to chloride was used to discriminate between WWTP effluent and road salting. This technique is based on the observation that WWTP effluent contains much more boron than road salt because of the prevalence of borate whitening agents found in WWTP effluent. Discrimination between road salt and softener salt is not possible because both processes use rock salt which originates from the evaporation of seawater. Figure 6 and Table 1 show the boron and chloride data in WWTP effluent, the Fox River, the pristine well (WK947) and the riparian wells (RL255 and RL256).

The WWTP value represents the average of 15 samples collected between winter 2008 and summer 2009 from all three upstream treatment plants. Fox River value is the average of 7 samples collected at the Fox 2 sampling site between spring 2007 and fall 2015. Riparian well data are individual samples collected sequentially between Spring 2007 and Fall 2015. The blue line is the mixing line between WK947 and seawater. The red line (demarcated in 10% increments) is the mixing line between WK947 and WWTP effluent. It is clear that the Fox River is a mix of pristine groundwater (WK947) and WWTP effluent. It is also clear that over time the riparian wells are pumping water that follows the effluent mixing line with very little influence of road or water softener salt. Figure 6 also shows that the Fox River at the Fox 2 sampling site contains 35 $\pm$25% effluent. This value correlates with previous estimations of effluent percentages based on stream flow mass balance calculations that report a maximum of 40% effluent at the Fox 2 site during annual low flow period (Holzbauer, 2010). Data in Table 1 and Figure 6 also indicates an ever increasing effluent signature in the riparian wells reaching a maximum of ~46% in both wells in the Fall of 2015. This figure is correlative with the percentages obtained from major ion chemistry.

Chloride load in the Fox River

The Teledyne-Isco automatic sampler collected daily river samples between April and October 2014. Additional hand samples were collected at the same site on the first warm days of the spring, when the temperature was above 0^{o}C and thawing of snow and ice cover was occurring. The sodium and chloride data obtained from this sampling effort are shown in Figure 7 along with the discharge as measured at the USGS gaging station located ~5 miles upstream.

The concentrations remained constant from April through October with average concentrations of 5.37 ± 1.12 mMol/L (123 ± 26 mg/L) sodium and 6.59 ± 1.08 mMol/L (234 ± 38 mg/L) chloride. This represents the ambient sodium and chloride concentration in in the river due to WWTP effluent. Dips in concentration were directly preceded by increases in discharge due to major precipitation events (blue ovals). This is surface flow dilution and indicates that sodium and chloride concentrations were not due to runoff from the landscape during the majority of the year but rather to WWTP effluent input.

In 2014 the spring melt occurred between March 7th and March 22nd. Concentrations during the spring melt were markedly higher, reaching maximum concentration s of 13.09 mMol/L (301 mg/L) sodium and

Sample Name	Collection Date	Boron (ppb)	Chloride (ppm)
Seawater		4450	19400
WK947	Sep-15	52	88
RL255	Apr-07	56	130
RL255	Sep-07	71	140
RL255	Jun-08	91	156
RL255	May-09	78	153
RL255	Sep-15	121	163
RL256	Apr-07	79	89
RL256	Sep-07	76	100
RL256	Jun-08	102	132
RL256	May-09	83	130
RL266	Sep-15	121	182
Fox 2 average (n=7)	Sep-08 through May-09	214 ± 61	242 ± 47
WWTP average (n =15)	Sep-08 through May-09	473 ± 77	532 ± 85

Table 1. Boron and chloride data from end member waters pertinent to the Waukesha wellfield. Error values are ± 1 standard deviation. Seawater concentrations are literature values.

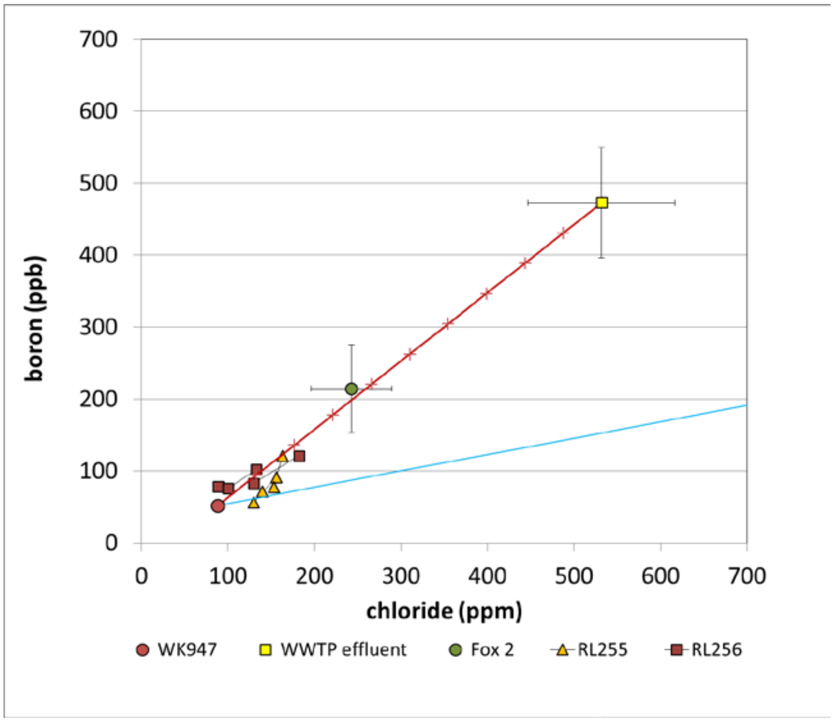

Figure 6. Boron and chloride concentrations in waters pertinent to the Waukesha well field. Error bars are ± 1 standard deviation of replicate measurements. No error bars are given for data points consisting of single measurements. Red line is the mixing line between pristine groundwater (WK947) and WWTP effluent demarcated in 10% intervals. Blue line is the mixing line between pristine groundwater and salt derived from seawater.

11.82 mMol/L(419 mg/L) chloride (purple oval). This is interpreted as an additional pulse of road salt entering the stream as a result of the initial melting of winter snow and ice. The spring melt concentrations reflect both the ambient contribution from WWTP effluent and the contribution from road salt. Concentrations of other ions (Ca^{2+}, Mg^{2+}, K^{+}, HCO_3^{-}, SO_4^{2-}) remain constant during the spring melt.

The percentage of the yearly load attributable to road salting was calculated by assuming the ambient loads observed between April and October remained constant and that these loads can be extrapolated throughout the remainder of the year. The road salt load is the difference between the extrapolated ambient March load and the measured March load (Equation 1).

$$Yearly\ Load\ due\ to\ road\ salt\ (\%) = \frac{\sum road\ salt\ load}{extrapolated \sum_{Apr-Oct} loads} * 100 \qquad \text{Eqn. 1}$$

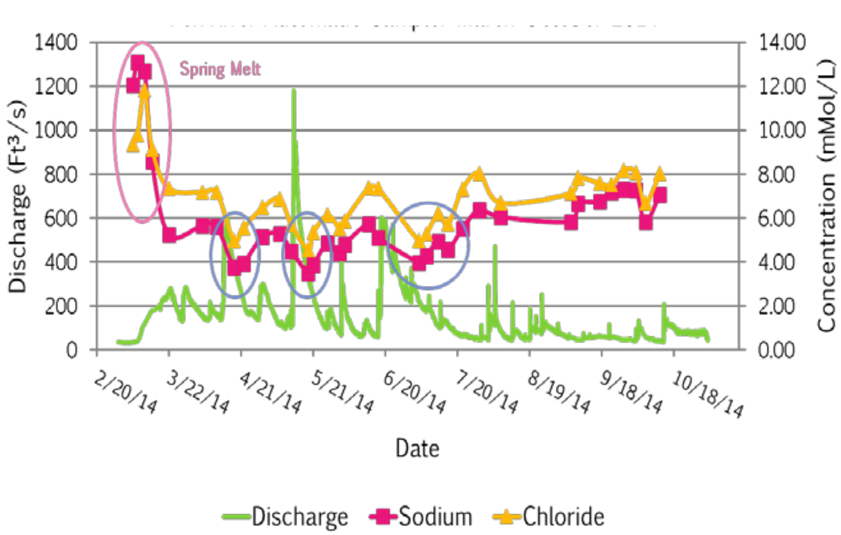

Figure 7. Sodium and chloride concentration in the Fox River at the Isco automatic sampler site in 2014 compared to discharge at USGS gage #05543830. Blue ovals indicate dips in concentration that are preceeded by large precipitation events.

The load of road salt entering the Fox River during the spring melt is 5% and 3% of the sodium and chloride yearly load respectively (Table 2). The road salt coming into the system is very small compared to the 95%-97% originating from WWTP effluent entering throughout the year. Road salt has a minimal impact on this system. This finding agrees with the previously mentioned boron:chloride data that also indicates very little effect of road salt on the Fox River.

<u>Stable isotopes</u>

The Fox River contains a mix of WWTP effluent and modern precipitation originating from baseflow out of the continuously recharged shallow aquifer. WWTP effluent from all three communities (Brookfield, Sussex and Waukesha) originates primarily from the deep sandstone aquifer. The deep aquifer contain Pleistocene age water which was recharged in a very cold climate and is therefore isotopically much lighter than modern water (Klump et al., 2008). The local meteoric water line (LMWL) used for this study was defined for Madison, Wisconsin (Swanson et al., 206). Figure 8 shows all the isotopic data collected between 2009 and 2015. The volume weighted average of all WWTP effluent samples (n=29) is $\delta^{18}O$ = -9.8$\pm$0.5‰ and δD = -66.3$\pm$4.1‰. This is in contrast to the average (n=37) of all three Waukesha wells including both riparian and pristine wells which is $\delta^{18}O$ =-9.1$\pm$0.1‰ and δD = -59.7$\pm$0.6‰. There is no trend over time in the isotopic signature of the shallow wells and furthermore there is no discernible difference between the pristine well and the two riparian wells in spite of the fact that river water is advancing into the wellfield. The reason for this is twofold. First, the isotopic variability of the Fox River

Spring Melt Load 2014								
Ion	Ca	Na	Mg	K	HCO_3	Cl	SO_4	NO_3
Avg. Measured Load in March (kg/day)	885	2158	425	9.5	3155	3543	705	162
Avg. Monthly Load from Apr - Oct (kg/day)	928	1356	422	43	2881	2646	664	151
Road Salt Load (kg/day)		802				897		
Road Salt Contribution to Annual Load		5%				3%		

Table 2. Measured loads in the Fox River. Calculation of road salt load is described in the text.

is much greater than is observed in the wells. This variability far exceeds the difference between WWTP effluent and pristine groundwater hence any mixing between these two endmembers cannot be rectified. The second reason is the lack of a short, well-defined flow path between river and riparian wells. Feinstein, et al. (2012) reported on a particle tracking simulation to determine the flow paths between the river bed and the RBI wells. Modelled flow paths are complex and were found to originate at distances as great as 300 m downstream for RL255 and 600 m downstream for RL256. River water does not follow a direct path from the river to the wells making this system unsuitable for rectifying a mixing trend . The mixing trend is further confounded by inconsistent pumping rates. As discussed previously, it is not clear that the amount of stream flow inducement has reached steady state (Figure 5) which further masks any potential change in the isotopic signatures of the RBI wells.

Isotopic data does illuminate behavior of the river itself. Samples collected upstream of all WWTP outfalls (Fox 0) fall along a line with a slope of 5.35 that intersects with the composition of pristine groundwater (Figure 8 inset). River water in this stretch is unaffected by WWTP effluent and during low flow conditions (when these samples were collected) it originates from pristine groundwater inflow that is subject to local evaporation. Evaporative effects on rivers in this climate cause the isotopic composition to diverge from the source water along a line that typically has a slope of five (Gat (1996); Gibson and reid (2010); Athanasopoulos et al. (2011)). Samples collected downstream of WWTP outfalls do not exhibit evaporative effects because of strong effect of mixing with isotopically light WWTP effluent.

The very large variation in isotopic composition observed in the river is due to seasonal climatic changes. The isotopically heaviest samples were all collected in summer (May, June, July) whereas the isotopically lightest samples were all collected in colder times of the year. This is particularly evident for the March samples collected during spring melt which display δD values less than -67‰. This phenomenon is true everywhere along the river, ie. all samples with δD values less than -67‰ are spring melt. In addition to cold conditions that prevail during initial snowfall, the partial melting of ice causes preferential melting of lighter isotopes, a process that results in extremely light isotopic signatures during the initial spring melt

Fecal bacteria tracers

There is always the concern that fecal bacteria may be transported into the wellfield along with effluent induced from the river itself. In order to investigate this concern, a single round of bacterial monitoring was performed during the Fall of 2014 and quantitative polymerase chain reaction (qPCR) analyses were

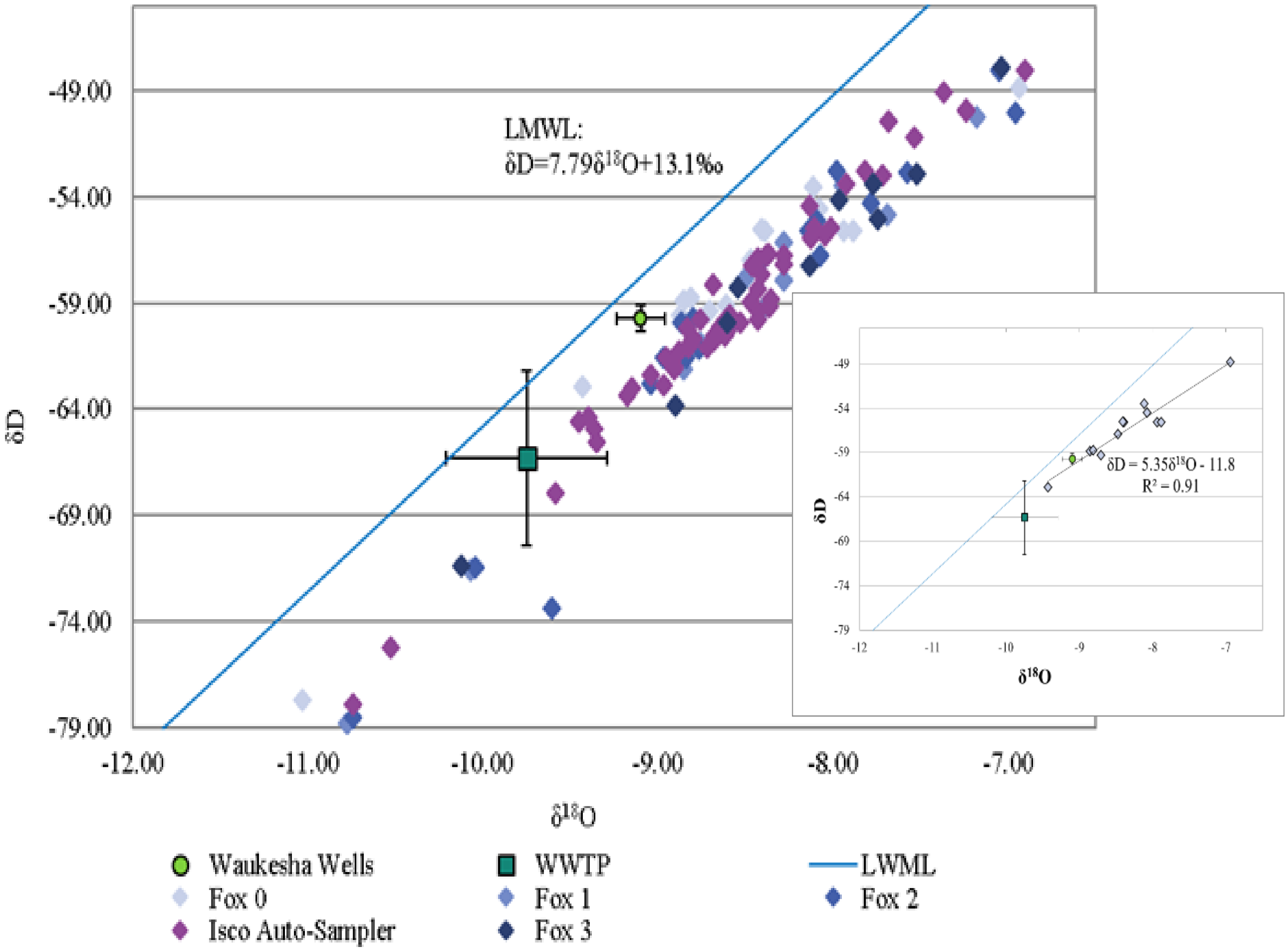

Figure 8. Hydrogen and oxygen stable isotopic signatures of samples collected between 2009 and 2015 in Fox River samples at sites 0, 1, 2, Isco Auto-Sampler, and 3. Waukesha wells RL255, RL256, and WK947 are represented as a single average (n=37) with ±1 standard deviation error bars. WWTP isotopic signature are represented as a volume weighted average (n=29) with ±1standard deviation error bars. Inset graph shows only samples upriver from all WWTP outfalls (Fox 0).

performed. Specific sequences present for ruminant, ecoli, enterococcus, lachnospireacie, and bacterioides, were quantified. Samples were taken from the three WWTPs, Fox 0, Fox 2, RL 255, RL 256 and WK 947 sites. A full tabulation of results and analytical protocols are given in Appendix B.

Ruminant tracers were not found in any of the samples, consistent with the fact that there are no active farms within the area.The general fecal tracers, enterococcus and E. coli were highest in Brookfield and Sussex WWTPs, followed by Fox 0, Fox 2, and then Waukesha WWTP. This indicates there is some kind of fecal material in all of these samples though not necessarily human fecal matter. There is a pet lodgedirectly adjacent to the Fox 0 site, which may be causing the high counts seen in these results. The human specific tracers (Bacteroidales and Lachnospiraceae) show a well-defined pattern of high counts in the effluent of all three WWTPs, lower counts in the downstream river site (Fox 2) and none in the upriver site (Fox 0). No fecal tracer bacteria of any type were found in any of the wells. There is no apparent transport of any fecal bacteria into the well field, consistent with the literature which finds minimal direct addition of foreign bacteria to an aquifer (Pang, 2009; Pang et al., 2007).

Pharmaceutical and personal care product tracers

One liter of sample was collected from the Sussex and Brookfield WWTPs, Fox 0, Fox 2, RL255, RL256 and WK947 sites during the spring 2015 sampling period for analysis 14 PPCP compounds at the UW-Steven's Point Water and Environmental Analysis Lab. A full tabulation of results and analytical protocols are given in Appendix B. Five compounds (carbamazepine, sucralose, sulfamethoxazole, trimethoprim and venlafaxine) were found in both WWTP effluent and in the downstream Fox river sample (Fox 2) and were absent in the upstream Fox river sample (Fox 0). These compounds serve as potential tracers of movement of river water into the well field. Of these, only sucralose is detected in the RBI wells (RL255 and RL256). None of the other tracer compounds are found in any well. Sucralose, with K_{ow} values 2 to 4 orders of magnitude less than the other tracers, is the one that moves most rapidly. Transport of the other tracer compounds is retarded by their propensity to sorb to aquifer solids and have not appeared as yet in the RBI wells.

CONCLUSION

A wide range of geochemical/hydrologic data was collected during during the course of this project. This data, combined with earlier geochemical and modelling studies on the same site, lead to the following set of conclusions with respect to the interaction between the RBI wells and the Fox river:

1) Fox River water is clearly entering the two RBI wells (RL 255 and RL256). The pristine well (WK947) is hydrologically separate from the river and exhibits invariant sodium and chloride levels. Estimates obtained from major ion composition and B/Cl ratios indicate that the RBI wells pumped a maximum of between 39% and 59% river water. This maximum was reached in late 2013 and has declined since. Flow modelling of the well field yields a slightly lower estimate (30% river water), but also indicates that the percentage of pumped river water is declining.

2) B/Cl ratios indicate that the source of sodium and chloride in the river, and therefore in the RBI wells, is dominantly WWTP effluent originating from the three upstream WWTPs. The effect of road salt on the river itself and on the RBI wells is minimal. 97%-95% of the annual sodium chloride load carried by the Fox river originates from WWTP effluent with the balance coming from road salt contributed during the annual spring melt.

3) Five PPCPs (carbamazepine, sucralose, sulfamethoxazole, trimethoprim and venlafaxine) were found in both WWTP effluent and the Fox river adjacent to the wellfield. Of these, only sucralose was detected in the RBI wells. Sucralose levels were below what would be expected based on the mixing ratios given in 1) above. Although sucralose is the most mobile of the PPCP contaminants found in the Fox river it still exhibits small amounts of transport retardation in aquifer sediments. More highly retarded contaminants will likely begin appearing in the RBI wells in the future.

4) qPCR data was collected and analyzed for the presence of fecal bacteria in the wellfield. Although both generic and human-specific fecal bacteria were found in the Fox river, no fecal bacteria was found in any well.

5) A detailed study of the stable isotopic signature of effluent, groundwater and river water indicate a large annual variability in the isotopic character of the Fox river in response to weather variations during the course of the year. Isotopically heavy water occurs in the late summer/fall and isotopically light water is found in the spring /early summer. Spring melt samples exhibit extraordinarily light isotopic compositions (δD values from -67‰ to -89‰). This wide variability precluded the use of stable isotopes as tracers of river water entering the RBI wellfield

REFERENCES

Athanasopoulos, P., Hendry, M., and Wassenaar, L., 2011, Isotope hydrology of precipitation, surface and ground waters in the Okanagan Valley, British Columbia: Canada. Journal of Hydrology, v. 411, p. 37-48.

Balkwill, D. L., and Ghiorse, W. C., 1985, Characterization of subsurfface bacteria associated with two shallow aquifers in Oklahoma: Applied and Environ. Microbiology, v. 50, p. 580-588.

Beyerle, U., Aeschbach-Hertig, W., Imboden, D. M., Baur, H., Graf, T., and Kipfer, R., 2000, A mass spectro- metric system for the analysis of noble gases and tritium from water samples: Environ. Sci. Technol., v. 34, no. 10, p. 2042-2050.

Buerge, I., and Poiger, T., 2011, Acesulfame: from sugar substitute to wastewater marker. CHIMIA: Chimia, v. 65, no. 3, p. 176-177.

Chapelle, F. H., 1992, Groundwater Microbiology and Geochemistry, New York, John Wiley and Sons, 424 pp. p.:

Feinstein, D. T., Fienan, M. N., Kennedy, J. L., Buchwald, C. A., and Greenwood, M. N., 2012, Development and Application of Groundwater/Surface-Water Flow Model using MODFLOW-NWT for the Upper Fox River Basin, Southeastern Wisconsin. United States Geological Survey Scientific Investigations Report 2012-5108. 124 pp.

Gat, J., 1996, Oxygen and hydrogen isotopes in the hydrologic cycle: Annual Review of Earth Planet Science, v. 24, p. 225-262.

Gibson, J., and reid, R., 2010, Stable isotope fingerprint of open-water evaporation losses and effective drainage area fluctuations in a subarctic shield watershed: Journal of Hydrology v. 381, p. 142-150.

Holzbauer, M., 2010, Tracking shallow groundwater anthropogenic effects in southeastern Wisconsin [MS]: University of Wisconsin-Milwaukee, 147 pp. p.

Kahle, M., Buerge, I., Muller, M., and Poiger, T., 2009, Pharmaceuticals and personal care products in the environment: hydrophilic anthropogenic markers for quantification of wastewater contamination in ground and surface waters: Environmental Toxicology & Chemistry, vol. 28, p. 2528-2536.

Klump, S., Cirpka, O., Surbeck, H., and Kipfer, R., 2008, Experimental and numerical studies on excess-air formation in quasi-saturated porous media: Water Res. Research, v. 44, no. W05402, p. 1-15.

Lisle, J. T., 2014, Survival of bacterial indicators and the functional diversity of native microbial communities in the Floridan Aquifer systen, South Florida. United States Geological Survey Open File Report 2014-1011,70 pp.

McIntosh, J. C., Garven, G., and Hanor, J. S., 2011, Impacts of Pleistocene glacialtion on large-scale groundwater flow and salinity in the Michigan Basin: Geofluids, v. 11, p. 18-33.

Pang, L., 2009, Microbial removal rates in subsurface media from published studies of foeld experiments and large intact soil cores: J. Environ. Quality, v. 38, p. 1531-1559.

Pang, L., McLeod, M., Aislabie, J., Simunek, J., Close, M., and Hector, R., 2007, Modeling transport of microbes in ten undisturbed soils under effluent irrigation: Vadose Zone J., vol. 7, p. 97-111.

SEWRPC, 2010, A Regional Water Supply Plan for Southeastern Wisconsin, Volume 1: Southeastern Wisconsin Regional Planning Commission Report number 52, 831 pp.

Swanson, S., Barh, J., and Potter, K., 206, A local Metoric Water Line for Madison, Wisconsin. : Wisconsin Geological and Natural History Survey Open File Report 2006-01.
White, D. C., Fredrickson, J. F., Gehron, M. H., Smith, G. A., and Martz, R. F., 1983, The groundwater aquatic microbiota: Biomass, community structure and nutritional status: Developments in Industrial Microbiology, v. 24, p. 189-199.
Wolf, L., Zwiener, C., and Zemann, M., 2012, Tracking artificial sweeteners and pharmaceuticals introduced into urban groundwater by leaking sewer networks: Science Total Environment, v. 430, p. 8-19.

APPENDIX A

Presentations

Fields-Sommers, L., Grundl, T., (March 2015) "Assessing the Effects of Riverbank Inducement on Groundwater Quality of a Shallow Aquifer in Southeastern Wisconsin", 39th Annual American Water Resources Association Wisconsin Section Meeting, Wisconsin Dells Conference, Oconomowoc, WI. published in annual proceedings volume.). ~80 attendees.

Fields-Sommers, L., Grundl, T. (May 2015) "Assessing the Effects of Riverbank Inducement on Groundwater Quality of a Shallow Aquifer in Southeastern Wisconsin", Society for Freshwater Science National Meeting, Milwaukee, WI. ~50 attendees.

Fields-Sommers, L., Grundl, T. (Fall 2015) "Assessing the Effects of Riverbank Inducement on Groundwater Quality of a Shallow Aquifer in Southeastern Wisconsin", Milwaukee Environmental Science Exchange, Milwaukee WI. ~50 attendees

Grundl, T., Fields-Sommers, L., Graham, J. (March 2016) "Groundwater-surface water interactions caused by pumping from a riverbank inducement well field", 40th Annual American Water Resources Association Wisconsin Section Meeting, Wisconsin Dells published in annual proceedings volume ~80 attendees.

Fields-Sommers, L., Grundl, T. (April 2016) "Assessing the Effects of Riverbank Inducement on Groundwater Quality of a Shallow Aquifer in Southeastern Wisconsin", Escuela Superior Politecnica de Litoral (Ecuador). ~50 attendees

Masters Thesis

Fields-Sommers, L. (2015) Assessing the Effects of Riverbank Inducement on a Shallow Aquifer in Southeastern Wisconsin, Masters Thesis School of Freshwater Sciences, UW –Milwaukee, 211 pp.

Funded Students

Laura Fields-Sommers (MS) is currently working full time at the Southeastern Regional Planning Commission in Wisconsin doing lake management planning

Jack Graham (MS) is currently employed full time by CH2M-Hill in Pensacola FL as a hydrogeologist

Student awards: Laura Fields-Sommers received two internal UW-Milwaukee awards during her tenure: Chancellor's Graduate Student Award and a Research Excellence Award.

Elevator speech

This work was a continuation of a larger project (funded by a private foundation) that looked at the feasibility of using riverbank infiltration as a way for Waukesha to obtain a reliable, radium free source of water other than Lake Michigan to augment their current radium-tainted water supply. The underlying hydrologic and geochemical data generated by the overall project, including this study, was used by the City of Waukesha, by a variety of Wisconsin environmental groups, by the WDNR and by the State of Michigan to assess the efficacy of this option as an alternative to Lake Michigan as a way to augment Waukesha's water supply. This work has clearly been central to the deliberations surrounding Waukesha's application for an exemption to the Great Lakes Compact.

APPENDIX B

Sample Collection Information

<u>Coordinates of Sampling Sites in Decimal Degrees</u>

Sampling Site	Latitude	Longitude
RL 255	42.959938	-88.279256
RL 256	42.961012	-88.279063
WK 947	42.961236	-88.289167
Fox 0	43.120068	-88.164715
Fox 1	43.011395	-88.234244
Fox 2	42.977690	-88.264797
Fox 3	42.876283	-88.210559
Auto Sampler	42.960951	-88.278707
Brookfield WWTP	433.052745	-88.177110
Sussex WWTP	43.126171	-88.216985
Waukesha WWTP	42.998190	-88.249151
Hygeia Spring	42.879817	-88.205125
Sussex Creek	43.102008	-88.210367
Root River	42.858027	-87.997586
Underwood Creek	43.042935	-88.056498
EM275	43.099327	-88.103161
IZ 385	43.063351	-88.183740
IZ 386	43.051841	-88.176827
SV 631	42.901237	-88.059776

Contact information for sampling sites

Municipality	Contact Person	Contact Number			
Waukesha Water Utility-Wells	Jeff Detro	Personal-262.490.4430 General-262.521.5272 JDetro@waukesha-water.com	RL255,#11	RL256,#12	WK947,#13
			3103 Saylesville Rd, Waukesha, WI		
Bookfield Wells	Mark Simon	262.796.6717	IZ385, #7	IZ386,#19	EM275,#28
	Mike Terry		Camelot 2	Industrial	Pilgrim Rd
			19700 Riverview Drive, Brookfield, WI		
St. Martins of Tours	Tom Breedom	414.333.4700	Available M-Th 5am-1pm 7963 S. 116th St, Franklin, WI		
Waukesha WWTP	Randy Thater	Office: 262.524.3631 Cell: 414.507.1139	600 Sentry Drive Waukesha, WI		
Brookfield WWTP	Rick Wenzel	262.787.3809 For Gate: 262.782.0199	21225 Enterprise Ave. Brookfield, WI		
Sussex WWTP	Jon Baumann	262.246.5184	N59 W23551 Clover Drive Sussex, WI		
City of Waukesha Director of Department of Parks, Recreation and Forestry	Ron Grall	262.524.3734 www.ci.waukesha.wi.us/parks RGrall@ci.waukesha.wi.us	1900 Aviation Drive Waukesha, WI 53188		
Waukesha Park System Manager	Duane Grimm	262.548.7807 dgrimm@waukeshacounty.gov	Waukesha County Department of Parks and Land Use 515 W. Moreland Blv. Room AC230 Waukesha, WI 53188		
Waukesha- water engineer	Katie Jelacic, P.E. Project Engineer 262-524-3587 Cell 262-349-6511				
Waukesha water utility	Main # 262-521-5272				

Well Construction Reports

WISCONSIN UNIQUE WELL NUMBER
SOURCE: WELL CONSTRUCTION **RL255**

State of Wi-Private Water Systems-DG/2
Department Of Natural Resources, Box 7921
Madison, WI 53707

Form 3300-77A
(Rev 12/00)

Depth 127 FT

Property Owner: WAUKESHA WATER UTILITY
Telephone Number: 262 - 521 - 5242
Mailing Address: 115 DELAFIELD ST
City: WAUKESHA | State: WI | Zip Code: 53188
County of Well Location: 2 68 WAUKESHA | Co Well Permit No: W | Well Completion Date: January 31, 2005

1. Well Location
C T=Town C=City V=Village of WAUKESHA | Fire#
Street Address or Road Name and Number: RIVER RD
Subdivision Name | Lot# | Block #
Gov't Lot or SE 1/4 of SW 1/4 of Section 20 T 6 N R 19 E
Latitude Deg. Min.
Longitude Deg Min.
Lat/Long Method GPS009

Well Constructor: WATER WELL | License #: 6685
Facility ID (Public): 26802380
Address: N87 W36051 MAPLETON ST
Public Well Plan Approval#: 2003779
City: OCONOMOWOC | State: WI | Zip Code: 53066
Date Of Approval: 12/03/2003
Hicap Well #: 67951 | Common Well #: 11 | 6 gpm/ft

2. Well Type 1 1=New 2=Replacement (See item 12 below) 3=Reconstruction
of previous unique well # ________ constructed in ______
Reason for replaced or reconstructed Well?
1 1=Drilled 2=Driven Point 3=Jetted 4=Other

3. Well Serves # of homes and or CITY
(eg: barn, restaurant, church, school, industry, etc.)
M M=Munic O=OTM N=NonCom P=Private Z=Other X=NonPot A=Anode L=Loop H=Drillhole
High Capacity: Well? Y Property? Y

4. Is the well located upslope or sideslope and not downslope from any contamination sources, including those on neighboring properties? Y
Well located in floodplain? N
Distance in feet from well to nearest: (including proposed)

1. Landfill
2. Building Overhang
3. 1=Septic 2= Holding Tank
4. Sewage Absorption Unit
5. Nonconforming Pit
6. Buried Home Heating Oil Tank
7. Buried Petroleum Tank
8. 1=Shoreline 2= Swimming Pool
9. Downspout/ Yard Hydrant
10. Privy
11. Foundation Drain to Clearwater
12. Foundation Drain to Sewer
13. Building Drain 1=Cast Iron or Plastic 2=Other
14. Building Sewer 1=Gravity 2=Pressure 1=Cast Iron or Plastic 2=Other
15. Collector Sewer: ___ units ___ in . diam.
16. Clearwater Sump
17. Wastewater Sump
18. Paved Animal Barn Pen
19. Animal Yard or Shelter
20. Silo
21. Barn Gutter
22. Manure Pipe 1=Gravity 2=Pressure 1=Cast iron or Plastic 2=Other
23. Other manure Storage
24. Ditch
25. Other NR 812 Waste Source

5. Drillhole Dimensions and Construction Method

Dia.(in.)	From (ft)	To (ft)
28.0	surface	70
24.0	70	127

Upper Enlarged Drillhole / Lower Open Bedrock
-- 1. Rotary - Mud Circulation
-- 2. Rotary - Air
-- 3. Rotary - Air and Foam
-- 4. Drill-Through Casing Hammer
-- 5. Reverse Rotary 28
X -- 6. Cable-tool Bit ___ in. dia
X -- 7. Temp. Outer Casing 24 in. dia 70 depth ft. Removed ? X
Other

8. Geology

Geology Codes	Type, Caving/Noncaving, Color, Hardness, etc	From (ft.)	To (ft.)
I	TOPSOIL	0	4
YC	SAND, GRAVEL, CLAY	4	10
CG	CLAY W/GRAVEL STONE	10	87
Y	SAND & GRAVEL	87	105
S	SAND	105	127

6. Casing Liner Screen

Dia. (in.)	Material, Weight, Specification Manufacturer & Method of Assembly	From (ft.)	To (ft.)
16.0	16 INCH X .375 INCH WALL ERW A53B LONESTAR WELDED 62.64	surface	90

Dia.(in.)	Screen type, material & slot size	From	To
16.0	16 INCH PS X .070 INCH SLOT 304 SS	90	125

9. Static Water Level
1.0 feet B ground surface A=Above B=Below

10. Pump Test
Pumping level 83.0 ft. below surface
Pumping at 490.0 GPM 5.0 Hrs

11. Well Is: A Grade 60 in. A=Above B=Below
Developed? Y
Disinfected? Y
Capped? Y

7. Grout or Other Sealing Material
Method: TREMIE PUMPED
Kind of Sealing Material | From (ft.) | To (ft.) | # Sacks Cement

12. Did you notify the owner of the need to permanently abandon and fill all unused wells on this property? Y
If no, explain

WISCONSIN UNIQUE WELL NUMBER **RL256**
SOURCE: WELL CONSTRUCTION

State of Wi-Private Water Systems-DG/2
Department Of Natural Resources, Box 7921
Madison, WI 53707

Form 3300-77A (Rev 12/00)

Depth 148 FT

Property Owner	WAUKESHA WATER UTILITY
Telephone Number	262 - 521 - 5242
Mailing Address	115 DELAFIELD ST
City	WAUKESHA
State	WI
Zip Code	53188
County of Well Location	68 WAUKESHA
Co Well Permit No	W
Well Completion Date	May 24, 2005
Well Constructor	WATER WELL
License #	6685
Facility ID (Public)	26802380
Address	N87 W36051 MAPLETON ST
Public Well Plan Approval#	2003799
City	OCONOMOWOC
State	WI
Zip Code	53066
Date Of Approval	12/03/2003
Hicap Well #	67952
Common Well #	12
gpm/ft	8

1. Well Location C T=Town C=City V=Village Fire#
of WAUKESHA
Street Address or Road Name and Number: RIVER RD
Subdivision Name / Lot# / Block #
Gov't Lot or SE 1/4 of SW 1/4 of Section 20 T 6 N R 19 E
Latitude Deg. Min.
Longitude Deg. Min.
Lat/Long Method GPS009

2. Well Type 1 — 1=New, 2=Replacement, 3=Reconstruction (See item 12 below)
of previous unique well # ________ constructed in ______
Reason for replaced or reconstructed Well?
1 — 1=Drilled 2=Driven Point 3=Jetted 4=Other

3. Well Serves # of homes and or CITY (eg: barn, restaurant, church, school, industry, etc.)
M — M=Munic O=OTM N=NonCom P=Private Z=Other X=NonPot A=Anode L=Loop H=Drillhole
High Capacity: Well? Y Property? Y

4. Is the well located upslope or sideslope and not downslope from any contamination sources, including those on neighboring properties? Y
Well located in floodplain? N
Distance in feet from well to nearest: (including proposed)

1. Landfill
2. Building Overhang
3. 1=Septic 2= Holding Tank
4. Sewage Absorption Unit
5. Nonconforming Pit
6. Buried Home Heating Oil Tank
7. Buried Petroleum Tank
8. 1=Shoreline 2= Swimming Pool
9. Downspout/ Yard Hydrant
10. Privy
11. Foundation Drain to Clearwater
12. Foundation Drain to Sewer
13. Building Drain 1=Cast Iron or Plastic 2=Other
14. Building Sewer 1=Gravity 2=Pressure 1=Cast Iron or Plastic 2=Other
15. Collector Sewer: ___ units ___ in . diam.
16. Clearwater Sump
17. Wastewater Sump
18. Paved Animal Barn Pen
19. Animal Yard or Shelter
20. Silo
21. Barn Gutter
22. Manure Pipe 1=Gravity 2=Pressure 1=Cast iron or Plastic 2=Other
23. Other manure Storage
24. Ditch
25. Other NR 812 Waste Source

5. Drillhole Dimensions and Construction Method

Dia.(in.)	From (ft)	To (ft)
30.0	surface	63
24.0	63	144

Upper Enlarged Drillhole / Lower Open Bedrock
- 1. Rotary - Mud Circulation
- 2. Rotary - Air
- 3. Rotary - Air and Foam
- 4. Drill-Through Casing Hammer
- 5. Reverse Rotary
- X 6. Cable-tool Bit 24 in. dia
- X 7. Temp. Outer Casing 24 in. dia 63 depth ft. Removed ? X
- Other

8. Geology

Geology Codes	Type, Caving/Noncaving, Color, Hardness, etc	From (ft.)	To (ft.)
_I_	TOPSOIL	0	3
_CM	CLAY W/SILT	3	23
T_S_	BROWN SAND	23	27
_P_	HARDPAN	27	34
_GM	GRAVEL W/SILT	34	39
_GC	GRAVEL W/CLAY	39	54
G_C_	CLAY-GRAY	54	63
_AG_	GRAVEL COARSE	63	90
_AS_	COARSE SAND	90	125
_MS_	MEDIUM SAND	125	130
_AS_	COARSE SAND	130	144
_MS	MEDIUM SAND W/SILT	144	147

6. Casing Liner Screen

Dia. (in.)	Material, Weight, Specification Manufacturer & Method of Assembly	From (ft.)	To (ft.)
16.0	16 INCH O.D. X .375 INCH WALL ERW	surface	62
16.0	A53-B LONESTAR LONESTAR WELDED 62.64 1 LBS 1 FT	89	102

Dia.(in.)	Screen type, material & slot size	From	To
16.0	16 INCH P.S. X .070 INCH SLOT 304 S.S. DOUBLE SCREEN	62	143

9. Static Water Level 2.9 feet A ground surface A=Above B=Below

10. Pump Test Pumping level 58.8 ft. below surface; Pumping at 494.0 GPM 24.0 Hrs

11. Well Is: A Grade 36 in. A=Above B=Below
Developed? Y
Disinfected? Y
Capped? Y

7. Grout or Other Sealing Material
Method TREMIE PUMPED
Kind of Sealing Material | From (ft.) | To (ft.) | # Sacks Cement

12. Did you notify the owner of the need to permanently abandon and fill all unused wells on this property? Y
If no, explain

WISCONSIN UNIQUE WELL NUMBER
SOURCE: ELECTRONICALLY SUBMITTED **WK947**

State of Wi-Private Water Systems-DG/2
Department Of Natural Resources, Box 7921
Madison, WI 53707

Form 3300-77A
(Rev 12/00)

Depth 105 FT

Property Owner	WAUKESHA WATER UTILITY
Telephone Number	262 - 521 - 5272
Mailing Address	115 DELAFIELD ST
City	WAUKESHA
State	WI
Zip Code	53188
County of Well Location	SE 68 WAUKESHA
Co Well Permit No	W
Well Completion Date	November 28, 2007
Well Constructor	SAM'S WELL DRILLING
License #	370
Facility ID (Public)	26802380
Address	PO BOX 150
Public Well Plan Approval#	2007-0043
City	RANDOLPH
State	WI
Zip Code	53956
Date Of Approval	03/07/2007
Hicap Well #	70084
Common Well #	13
(specific capacity)	12.8 gpm/ft

1. Well Location T T=Town C=City V=Village of WAUKESHA Fire#
Street Address or Road Name and Number: SAYLESVILLE RD
Subdivision Name: RIVERS CROSSING Lot# Block #
Gov't Lot or SE 1/4 of SE 1/4 of
Section 19 T 6 N R 19 E

2. Well Type 1 1=New 2=Replacement 3=Reconstruction (See item 12 below)
of previous unique well # ________ constructed in _____
Reason for replaced or reconstructed Well?
1 1=Drilled 2=Driven Point 3=Jetted 4=Other

3. Well Serves # of homes and or (eg: barn, restaurant, church, school, industry, etc.)
M M-Munic O-OTM N-NonCom P-Private Z-Other X-NonPot A-Anode L-Loop H-Drillhole
High Capacity: Well? Y Property? Y

4. Is the well located upslope or sideslope and not downslope from any contamination sources, including those on neighboring properties? Y
Well located in floodplain? N
Distance in feet from well to nearest: (including proposed)

1. Landfill
2. Building Overhang
3. 1=Septic 2= Holding Tank
4. Sewage Absorption Unit
5. Nonconforming Pit
6. Buried Home Heating Oil Tank
7. Buried Petroleum Tank
8. 1=Shoreline 2= Swimming Pool
9. Downspout/ Yard Hydrant
10. Privy
11. Foundation Drain to Clearwater
12. Foundation Drain to Sewer
13. Building Drain 1=Cast Iron or Plastic 2=Other
14. Building Sewer 1=Gravity 2=Pressure 1=Cast Iron or Plastic 2=Other
15. Collector Sewer: ___ units ___ in . diam.
16. Clearwater Sump
17. Wastewater Sump
18. Paved Animal Barn Pen
19. Animal Yard or Shelter
20. Silo
21. Barn Gutter
22. Manure Pipe 1=Gravity 2=Pressure 1=Cast iron or Plastic 2=Other
23. Other manure Storage
24. Ditch
25. Other NR 812 Waste Source

5. Drillhole Dimensions and Construction Method

Dia.(in.)	From (ft)	To (ft)
24.0	surface	80
16.0	80	105

Upper Enlarged Drillhole / Lower Open Bedrock
- 1. Rotary - Mud Circulation
- 2. Rotary - Air
- 3. Rotary - Air and Foam
- 4. Drill-Through Casing Hammer
- X 5. Reverse Rotary
- 6. Cable-tool Bit ____ in. dia
- X 7. Temp. Outer Casing 24 in. dia 80 depth ft. Removed ? X
- Other

8. Geology

Geology Codes	Type, Caving/Noncaving, Color, Hardness, etc	From (ft.)	To (ft.)
C	Clay	0	8
Y	Sand & Gravel	8	32
Z	Clay & Gravel	32	85
Y	Sand & Gravel	85	105

6. Casing Liner Screen

Dia. (in.)	Material, Weight, Specification Manufacturer & Method of Assembly	From (ft.)	To (ft.)
16.0	STD BLK, PIPE, .375 WALL, P.E., A53B SEAH API5LB	surface	86

Dia.(in.)	Screen type, material & slot size	From	To
16.0	40 SLOT JOHNSON TELESCOPING W/KPACKER	83	105

9. Static Water Level 15.0 feet B ground surface A=Above B=Below

10. Pump Test Pumping level 62.0 ft. below surface Pumping at 600.0 GPM 20 Hrs

11. Well Is: A Grade 24 in. A=Above B=Below
Developed? Y
Disinfected? Y
Capped? Y

7. Grout or Other Sealing Material
Method: Tremie Pipe - Pumped

Kind of Sealing Material	From (ft.)	To (ft.)	# Sacks Cement
Neat cement grout	surface	76.0	210 S
BENTONITE CHIPS	76.0	78.0	2

12. Did you notify the owner of the need to permanently abandon and fill all unused wells on this property?
If no, explain

13. Initials of Well Constructor or Supervisory Driller JVG Date Signed 11/28/07
Initials of Drill Rig Operator (Mandatory unless same as above) RH Date Signed 11/28/07

Additonal Comments? WK Variance Issued? Y
Owner Sent Label? Y More Geology?

Batch 888888888

Fecal bacteria sampling/analytical protocol and results

A single round of bacterial monitoring was performed during the Fall of 2014. One liter sample was taken from the three WWTPs, Fox 0, Fox 2, RL 255, RL 256 and WK 947 sites. The samples were collected in sterile 1L Nalgene bottles with as little air as possible, kept on ice and filtered within 6 hours of collection. Glassware and associated utensils were prepared using UV sterilization for 15 min. The samples were filtered with 0.22 sterile 47mm EMD Millipore Microbiological Analysis Membrane Filters a vacuum manifold set at 20 kpa. The filter papers were kept, rolled, and placed in teflon tubes and frozen at -80^{o}C until analysis. Analysis was completed at the UWM School of Freshwater Science using Ultra Clean Mega Prep soil DNA kit (MoBio Laboratories Inc., Solana Beach, CA) to extract DNA for quantitative polymerase chain reaction (qPCR). Specific sequences present for ruminant, ecoli, enterococcus, lachnospireacie, and bacterioides, were quantified. Results are given in Table B1.

	Bacteroidales	**Lachnospiraceae**	**Enterococcus**	**E. coli**	**Ruminant**
Brookfield WWTP	431657	746381	226545	20560	0
Waukesha WWTP	8124	3623	7459	566	0
Sussex WWTP	25272	27762	99718	1975	0
Fox 0 (upriver)	0	0	9809	275	0
Fox 2 (downriver)	2833	2398	9697	579	0
RL 255 (RBI well)	0	0	0	0	0
RL 256 (RBI well)	0	0	0	0	0
WK 947 (pristine well)	0	0	0	0	0

Table B1. qPCR fecal bacteria counts for selected sample sites. Measurement units are colony number /100mL

PPCP sampling protocol and results

One liter of samples were collected for PPCP analysis from sampling sites during the spring 2015 sampling period. The samples were collected in sterile 1L Nalgene bottle, with as little air as possible, kept on ice for a maximum of 4 hours after collection. The samples were filtered with 0.2µm sterile regenerated cellulose filter via a vacuum pump set at 20 kpa. Filtrate was stored in amber glass bottles, with Teflon caps, and kept at 4ºC and shipped same day delivery to University of Wisconsin- Steven's Point Water and Environmental Analysis Lab. Results are given in Table B2. Acesulfame samples exhibited a low extraction efficiency therefore acesulfame values are only semi-quantitative.

PHARMACEUTICALS AND PERSONAL CARE PRODUCTS

All sample concentrations and limits of detection (LOD) are reported in parts per trillion (ng/L).

COMPOUND	Lowest limit of detection	Fox River 0	Waukesha WWTP	Sussex WWTP	Fox River 2	Well RL 255	Well RL 256	Well WK 947
Acesulfame (artificial sweetener)	*5.0^{B}*	*9.3*	*36.2*	*47.3*	*238.6*	*171.1*	*83.3*	*16.0*
Sucralose (artificial sweetener)	25	175.4	31983	23316	3342	416.4	774.8	<LOD
Caffeine (stimulant)	12.0	13.1	<LOD	19.5	87.2	<LOD	14.6	<LOD
Benzoylecgonine (cocaine metabolite)	5^{E}	<LOD	<LOD	31.2	5.7	<LOD	<LOD	<LOD
Carbamazepine (anti-epileptic)	2.0	<LOD	98.6	452.6	57.1	<LOD	<LOD	<LOD
Trimethoprim (human antibiotic)	5^{E}	<LOD	50.2	583.0	37.4	<LOD	<LOD	<LOD
Sulfamethoxazole (human antibiotic)	5^{E}	<LOD	483.9	816.2	338.4	<LOD	<LOD	<LOD
Venlafaxine (antidepressant)	5^{E}	<LOD	154.1^{A}	500.6	125.6	<LOD	<LOD	<LOD
Saccharin (artificial sweetener)	25^{E}	<LOD	<LOD	<LOD	31.5	<LOD	<LOD	<LOD
Cotinine (nicotine metabolite)	3.0	<LOD	<LOD	22.1	18.8	5.1	<LOD	<LOD
Paraxanthine (caffeine metabolite)	5.0	<LOD	<LOD	<LOD	16.9	<LOD	10.2	<LOD
Acetaminophen (analgesic)	35^{E}	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Sulfamethazine (bovine antibiotic)	1.0	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Triclosan (antimicrobial)	75	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

DATA FLAGS:

B = extraction efficiency is low therefore acesulfame values are not quantitative

E = Estimated

A = Sample concentration greater than calibrated range

Table B2. PPCP results from the UW Stevens Point Environmental Lab. < LOD means this compound was not detected at a level above limit of detection