Groundwater Research Report
WR01R006

IMPACTS OF PRIVATELY SEWERED SUBDIVISIONS ON GROUNDWATER QUALITY IN DANE COUNTY, WISCONSIN

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Impacts of Privately Sewered Subdivisions on Groundwater Quality in Dane County, Wisconsin

Final Report to the University of Wisconsin Water Resources Institute

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PROJECT SUMMARY

Title: **Impacts of Privately Sewered Subdivisions on Groundwater Quality in Dane County, Wisconsin**

Project ID: **R/UW-OSW-001**

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Background/Need: Urban development of rural areas is a significant land-use issue in Wisconsin and in many other parts of the United States. Septic tank and leach field treatment of wastewater can release contaminants such as nitrate, bacteria, viruses, and hazardous household chemicals to groundwater systems, posing potential threats to nearby wells and surface water. Potential groundwater contamination is often cited as justification for discouraging or prohibiting new unsewered rural developments, particularly in environmentally sensitive areas with high water tables or shallow bedrock, yet few field studies are available to document groundwater impacts.

Objectives: This project was initiated as a long-term monitoring study to document groundwater conditions before, during, and after construction of an unsewered rural subdivision that employs alternative on-site wastewater treatment technologies.

Methods: Site investigations consisted of hydrogeologic studies and water sampling with the goals of understanding the geology of the site, local groundwater movement, and background groundwater quality. Shallow piezometers and deeper bedrock wells were used to characterize the field site and to sample for major ions, indicator species, and atrazine. Isotopes of nitrogen were used to distinguish nitrate sources.

Results and Discussion:

Two aquifers are present at the site – a shallow unlithified aquifer composed of glacial sediment and a bedrock aquifer. Water levels in site wells ranged from 7 to 54 feet below the land surface. Most recharge occurs during the spring months, with declining water levels the rest of the year. During spring recharge, the aquifer responds rapidly to

precipitation, snowmelt, and ground thaw, although the magnitude of this response varies with location across the field site. Prior to subdivision construction almost all of the water samples collected from shallow wells at the Savannah Valley site showed evidence of human impact, as median values of nitrate-N (6.2 mg/L), sodium (17.0 mg/L), chloride (19.3 mg/L), and conductivity (821 μS/cm) were much higher than would be expected in an undeveloped area. Significant temporal and spatial variability in groundwater chemistry existed across the field site prior to subdivision construction. This variability can be explained by 1) seasonal variations in recharge, 2) local loading patterns, 3) aquifer heterogeneities, and 4) surface topography. Groundwater nitrate beneath the Savannah Valley subdivision site appears to have originated from both synthetic and organic (cow manure) fertilizers, as the measured $\delta^{15}N$ values fall between the typical values for the two sources.

Conclusions/Implications/ Recommendations:

For this study we installed monitoring equipment and acquired nearly two years of groundwater monitoring data prior to the construction of new homes at a rural subdivision site in south-central Wisconsin. The most important finding is the high variability - in both space and time - of groundwater quality across this relatively small subdivision site. Concentrations of chemical parameters just below the water table exceeded drinking water standards for nitrate and atrazine in some wells and showed evidence of land-use impacts (agricultural use and highway salting) in many wells. Concentrations in deeper bedrock wells, although lower and less variable, also showed evidence of impacts from land use. Groundwater monitoring should continue at the Savannah Valley site as the subdivision is developed and septic systems come into use. The background data collected prior to development provides a necessary benchmark against which to compare future land-use impacts.

Related Publications :

Wilcox, J.D. 2003. Variability of groundwater chemistry in an agricultural setting and implications for assessing impacts of land use change. University of Wisconsin-Madison. M.S. Thesis. 121p.

Key Words: Groundwater, subdivisions, nitrate, land use

Funding: University of Wisconsin System, Madison Area Builders Association

INTRODUCTION

Motivation

Urban development of rural areas is probably the most significant land-use issue in Wisconsin and in many other parts of the United States. Although new residential developments near urban centers typically use city water and sewer services, rural developments usually rely on private water-supply wells and on-site wastewater-treatment systems. Conventional septic tank and leach field treatment of wastewater can release contaminants such as nitrate, bacteria, viruses, and hazardous household chemicals to groundwater systems, posing potential threats to nearby wells and surface water. Potential groundwater contamination is often cited as justification for discouraging or prohibiting new unsewered rural developments, particularly in environmentally sensitive areas with high water tables or shallow bedrock.

New on-site treatment technologies have been developed in recent years to more effectively treat domestic wastewater. In 2000, the State of Wisconsin adopted Chapter Comm 83 (Wisc. Adm. Code, 2000), which permits the use of these alternative systems in areas where conventional systems are prohibited. To date, there have been few field studies to assess the performance of these systems.

This project was initiated as a long-term monitoring study to document groundwater conditions before, during, and after construction of an unsewered subdivision that employs alternative on-site wastewater-treatment technologies. This report summarizes the first stage of that project by documenting the preconstruction groundwater conditions that have resulted from previous agricultural land use. It also discusses the implications of these preconstruction results for identifying and interpreting changes that result from conversion of agricultural land to an unsewered subdivision.

Background Information

In response to concern over uncontrolled residential development in Dane County, Wisconsin, then-County Executive Rick Phelps issued a moratorium on the construction of new unsewered subdivisions in 1995. This, in effect, limited concentrated residential development to the urban fringe where it is economical to connect to municipal water and sewer systems. As a result, rural development currently accounts for only about one-eighth of new housing units in the county (Preboski, 2003).

In an effort to ease tension over land-use decisions and to address the increasing demand for housing options beyond the urban fringe, current Dane County Executive Kathleen Falk reached a formal agreement with the Madison Area Builders Association (MABA) and the Realtors Association of South Central Wisconsin (RASCW) in 1998. MABA and RASCW agreed to support an open-space referendum to acquire county parklands; County Executive Falk agreed to work with the MABA and RASCW on a pilot rural subdivision project of up to 30 new homes. The terms of the agreement stated that the new homes would use new-technology wastewater-treatment systems and be part of a 10-year groundwater-monitoring project intended to determine the effectiveness of the treatment systems and the impact of rural residential development on regional groundwater quality. In 2000, the Wisconsin Groundwater Research Advisory Council, with the support of Dane County and the MABA, funded a two-year research study to initiate this long-term monitoring. This report summarizes the initial two-year study. A Master's thesis by Wilcox (2003) contains additional details and data.

Site Selection and History

In the summer of 2001, Savannah Valley, a 78-acre parcel about 4 miles east of downtown Sun Prairie, Wisconsin, was chosen as the site for this pilot project (Figure 1). The surrounding area is predominantly agricultural, although Drover's Woods, an existing 54-home unsewered subdivision, is located about 1 mile to the east. When selected for this project, the site contained farmed and wooded areas as well as a small wetland. Its agricultural history dates back at least a century, with corn, soybeans, wheat, and hay as the dominant crops in recent years. A drain tile beneath the center of the property empties into a drainage ditch just north of the site. Overall, the site has rolling topography; two glacial kames provide the greatest relief.

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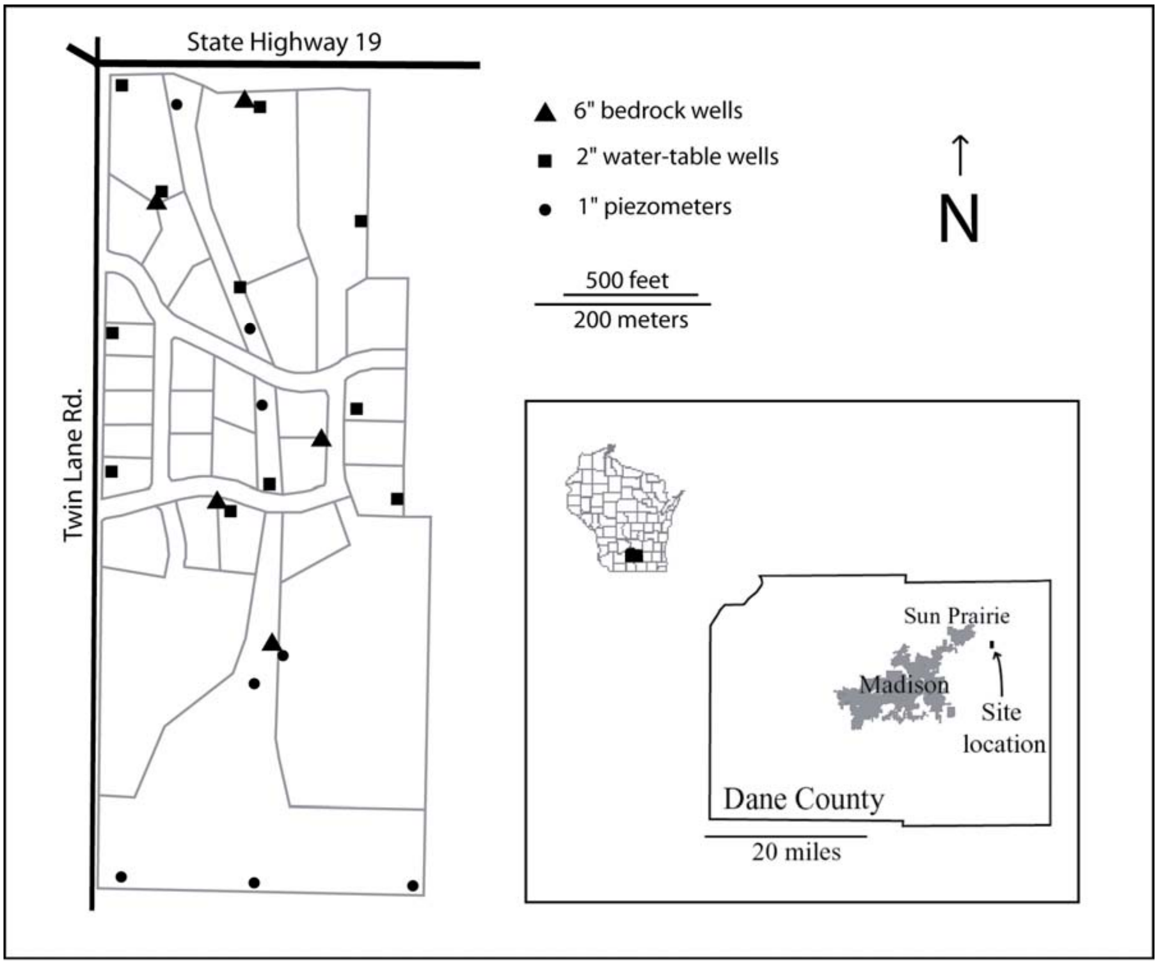

Figure 1. Location, layout, and monitoring well locations for the Savannah Valley subdivision site.

The final plat for a 30-home subdivision was approved in the summer of 2002. Site improvement began in September 2002, and construction of new homes began in early 2003. Of the 30 lots, 10 will use conventional wastewater-treatment systems; the remaining 20 will use alternative, new-technology treatment designs.

PROCEDURES AND METHODS

Site investigations consisted of hydrogeologic studies and water sampling with the goals of understanding the geology of the site, local groundwater movement, and background groundwater quality. The Wisconsin Geological and Natural History Survey installed 11 water-table monitoring wells in October and November 2001. Eight additional piezometers were installed by the U.S. Geological Survey in December 2002. Six of the water-table wells and five of the piezometers were instrumented with pressure transducers to collect hourly water level and temperature data. Five deep bedrock wells were also installed at the subdivision site using air-rotary techniques. Three of these wells will be converted to private water-supply wells as houses are built, and two will remain as nonpotable monitoring wells. All monitoring well locations are shown in Figure 1. Caliper, gamma radiation, fluid resistivity, and fluid temperature logs were collected for each of the five bedrock wells, and slug tests were conducted in most wells to estimate hydraulic conductivity. Monitoring wells were sampled regularly beginning in late 2001 for major ion concentrations, pH, temperature, and electrical conductivity. Ten private residential wells were sampled from rural homes near the Savannah Valley subdivision site in June 2002. An additional eight private wells were sampled from Drovers Woods subdivision located about a mile to the east. All wells were sampled for atrazine in May 2002, and nitrate-nitrogen isotope analyses were performed on seven water samples collected in October 2002. A rain gauge was installed to collect hourly precipitation data, and a datalogger was used to collect hourly conductivity data from the drain tile effluent.

RESULTS AND DISCUSSION

Site Geology

The site is characterized by a thin (0-5 ft) silt-loam soil overlying a sequence of unlithified glacial sediments belonging to the Horicon Member of the Holy Hill Formation. This unit is composed primarily of sandy gravel and interbedded sands and gravels, although finer sediments are also present. Grain size ranges from fine clays to erratic boulders more than 10 ft wide. A 15 ft thick clay layer at the southern boundary of the site thins northward and overlies coarser sands and gravels. The depth to bedrock ranges from 20 ft along the western ridge to approximately 70 ft below the kames on the northern edge of the site.

The uppermost bedrock unit is the St. Peter Formation, a very clean, fine- to medium-grained sandstone of Ordovician age. The St. Peter is more than 50 ft thick along the western ridge near Twin Lane Road, but absent over the rest of the site, where the uppermost bedrock unit is the Prairie du Chien Group. The Prairie du Chien is a sandy dolomite identified by the presence of oolites and traces of chert (Peters, 2003). The underlying Jordan and St. Lawrence Formations are composed primarily of dolomitic sandstones and together make up the Trempeleau Group. The Tunnel City Group lies below the St. Lawrence and represents the oldest bedrock unit reached by drilling at the site. It is similarly composed of fine- to medium-grained dolomitic and glauconitic sandstone. Figure 2 is a general cross-section through the Savannah Valley subdivision site showing the approximate thicknesses of bedrock units reached by drilling.

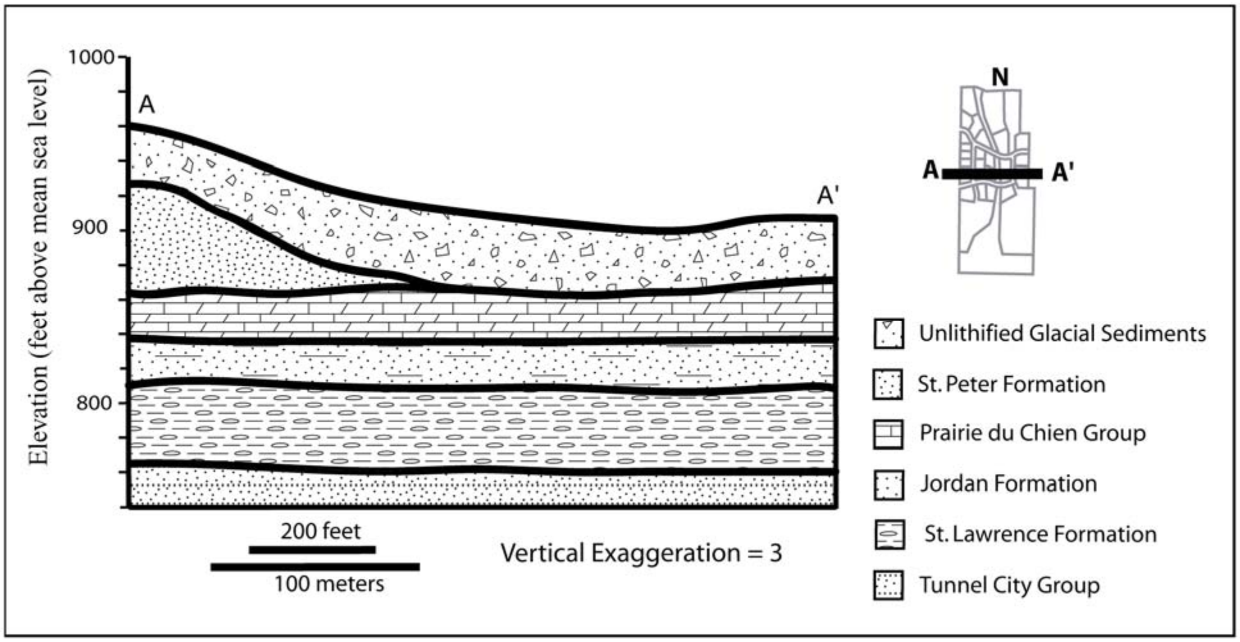

Figure 2. General stratigraphic cross section of the Savannah Valley subdivision site.

Site Hydrogeology

Two aquifers are present at the site - a shallow unlithified aquifer composed of glacial sediment and a bedrock aquifer composed of the bedrock units discussed above. Water levels in site wells ranged from 7 to 54 ft below the land surface. Static water levels obtained from local well construction reports suggest that regional groundwater flow is from west to east. Locally, groundwater flow converges towards a surface ditch just north of the site across Highway 19. The drain tile running beneath the site appears to have minimal impact on groundwater flow, and the tile and the connected drainage ditch were dry for much of the study period. The drain tile was active during the late spring and early summer recharge period and throughout the winter of 2001-2002, and might affect groundwater flow direction during wetter years when the water table is higher. However, during the course of this study, the configuration of the water table remained relatively constant (Figure 3).

Overall, groundwater flow is relatively rapid through the glacial aquifer, with horizontal velocities on the order of 1 to 2 ft/day. Vertical hydraulic gradients between nested wells ranged from -0.03 to -0.20, corresponding to downward velocities of 0.1 to 0.5 ft/day. Hydrographs for the instrumented water-table wells show that most recharge in the unlithified aquifer occurs during the spring months, with declining water levels the rest of the year. During spring recharge, the aquifer responds rapidly to precipitation, snowmelt, and ground thaw, although the magnitude of this response varies with location. In 2002, the shallow aquifer received recharge from mid-February through mid-June; however, after an extremely dry winter, water levels did not begin to rise significantly in 2003 until May. Water level rise in the shallow bedrock aquifer occured later and over a longer time than in the unlithified aquifer. Water levels in all monitoring wells were lower in early 2003 than they were at the same time in 2002, which is not surprising because the fall and winter of 2002 were much drier than in 2001.

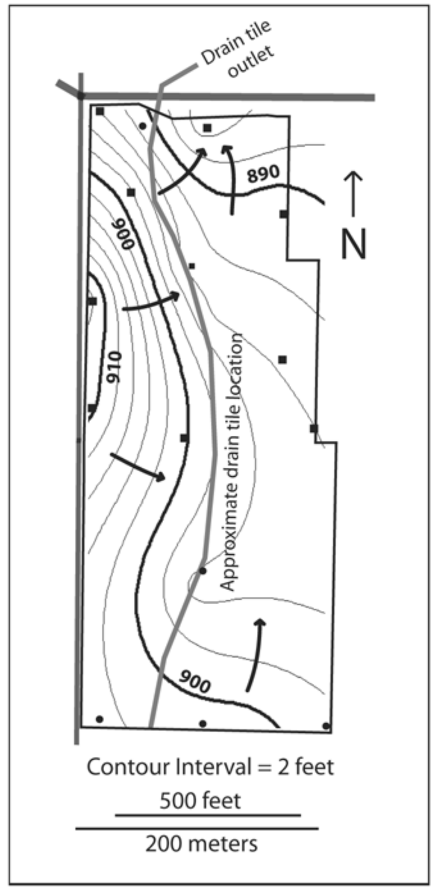

Figure 3. Water table map December 20, 2002

General Groundwater Chemistry

Reactions with dolomitic aquifer materials are the primary controls on groundwater chemistry in the area. Most of the water samples contained elevated calcium, magnesium, and bicarbonate concentrations. Elevated concentrations of nitrate, sodium, chloride, sulfate, and atrazine were measured in some of the wells, although concentrations of these constituents were highly variable in space and time. Selected water-chemistry data collected from the three well sets are listed in Table 1; a Master's thesis by Wilcox (2003) contains the complete chemical data set for this project.

Almost all of the water samples collected from shallow wells at the Savannah Valley site showed evidence of human impact; median values of nitrate-N (6.2 mg/L), sodium (17.0 mg/L), chloride (19.3 mg/L), and conductivity (821 µS/cm) were much higher than would be expected in an undeveloped area. For comparison, Trojan et al. (2003) found median levels of 0.6 mg/L, 5.6 mg/L, 1.8 mg/L, and 442 µS/cm, respectively, for these constituents beneath undeveloped forest or preservations areas in the Anoka Sand Plain in Minnesota.

Table 1. Selected water-quality data

Parameter	*Number of samples*	*Minimum*	*Maximum*	*Average*	*Standard Deviation*
	Savannah Valley water table wells				
Nitrate[1]	97	< 0.1	36.4	8.7	7.7
Chloride[2]	97	0.3	414.2	46.9	75.4
Atrazine[3]	11	< 0.1	0.8	0.3	0.3
Conductivity[4]	97	531	1839	904	239
	Savannah Valley bedrock wells				
Nitrate[1]	20	< 0.1	12.6	5.2	3.6
Chloride[2]	20	< 0.1	70.0	23.1	21.4
Atrazine[3]	5	< 0.1	0.3	0.2	0.1
Conductivity[4]	20	592	921	754	100
	Drovers Woods subdivision residential bedrock wells				
Nitrate[1]	8	< 0.1	8.8	6.3	2.9
Chloride[2]	8	0.3	35.9	19.4	11.3
Conductivity[3]	8	540	823	739	91
	Rural residential bedrock wells				
Nitrate[1]	10	0.2	25.6	8.2	8.0
Chloride[2]	10	4.4	76.8	27.6	23.1
Conductivity[3]	10	664	1025	835	148

* Concentrations are listed as: [1]mg/L nitrate-nitrogen, [2]mg/L, [3]µg/L, and [4]µS/cm at 25° Celsius.

Atrazine concentrations measured in the Savannah Valley wells were comparable to those measured in a recent study in Dane County. In that study, atrazine was detected in about 45 percent of rural wells tested, with atrazine and metabolite concentrations of 0.54 µg/L (Dane County Regional Planning Commission, 1999). Chloride and nitrate concentrations measured in many of the Savannah Valley wells also fell within the range of values measured elsewhere in the county. However, concentrations in some wells were much higher, and several wells had nitrate-N concentrations above the federal drinking water enforcement standard of 10 mg/L. It is particularly important to document the preconstruction concentrations of nitrate and chloride because these are among the principal contaminants in domestic wastewater. An understanding of the temporal and spatial variability of these constituents is essential to detect any changes in groundwater chemistry once homes are constructed.

Chemical Variability in Water-Table Wells

Significant temporal and spatial variability in groundwater chemistry existed across the field site prior to subdivision construction. This variability can be explained by 1) seasonal variations in recharge, 2) local loading patterns, 3) aquifer heterogeneities, and 4) surface topography.

Seasonal recharge. Seasonal fluctuations in recharge appear to be the major control on temporal variations in groundwater chemistry. As water levels rose rapidly during the spring months, concentrations of nitrate and chloride in many water-table monitoring wells decreased. The “dilution effect” by infiltrating snowmelt and precipitation in spring seems to have the greatest effect where the water table is closest to the ground surface. For example, nitrate-nitrogen levels in MW-11 decreased dramatically following the spring recharge season in 2002, and then rose above 20 mg/L again by the end of summer. Concentrations did not drop as much in May 2003, probably because recharge and dilution were limited during a dry winter and spring. Chloride concentrations in well MW-08 were typically around 100 mg/L. However, concentrations increased dramatically in the early spring 2002 when road salt applied during the previous winter reached the water table. By late spring, chloride concentrations were diluted to well below 100 mg/L before rising again by the end of summer.

Local loading patterns. Local loading patterns are a significant control on shallow groundwater chemistry. Fertilizers and road salt were the two local sources of contaminants at this site. Water-table wells at the edge of or beyond the cropped area had consistently lower nitrate concentrations than those in the middle of the fertilized field. Meanwhile, wells drilled near Highway 19 or Twin Lane Road, both of which were salted with NaCl during the winter months, had the highest sodium and chloride concentrations at the site. Both examples illustrate how local loading patterns can affect shallow groundwater chemistry.

Aquifer heterogeneities. Small-scale heterogeneities may play a large role in determining the relative distribution of contaminants at this site. For example, two wells (MW-02 and MW-10) are screened at about the same elevation and located along the eastern boundary of the site. However, samples collected from the two wells had distinctly different chemical compositions (Table 2). Levels of nitrate in well MW-02, which is cased in medium to coarse sand (K=5.6 ft/d), were much higher and more variable than in MW-10, which is cased in clay-rich sand (K=0.2 ft/day). It is likely that nitrate applied at the ground surface near both wells has a shorter transit time to groundwater through the coarse sediments near MW-02. Well MW-10 also had consistently higher sulfate levels than any of the other wells, probably due to the weathering of sulfide minerals in the surrounding clay lens.

Table 2. Selected chemical analyses of water samples from wells MW-02 and MW-10[1].

	NO_3-	Cl-	SO_4^{2-}	Na	K	Hardness	Mn	Fe	Alk	TDS
MW-02	19.5	4.9	5.6	4.3	2.1	378	0.0	0.0	283	556
MW-10	3.4	2.9	58.1	9.9	3.2	338	0.3	0.0	247	497

[1] Concentrations are median values in mg/L, except for hardness and alkalinity (mg/L as $CaCO_3$) and NO_3^- (mg/L as nitrogen).

Surface topography. Contaminant concentrations appeared to be elevated at low points in the landscape. Wells located at some of the topographically lowest points of a cropped field had the highest nitrate and atrazine concentrations. One reason for this correlation could be that runoff of applied fertilizers resulted in focused recharge of contaminants at topographic lows. This process has been documented in the sand plains of Minnesota (Delin and Landon, 2002). Another possible explanation is that because the water table is closer to the ground surface at topographic lows, groundwater is more susceptible to contaminants applied at the surface in those locations.

Chemical Variability in Bedrock Wells

Spatial variations in water chemistry observed for samples from bedrock wells can be related to casing depth and agricultural loading rates. Water from rural residential bedrock wells not located within Savannah Valley or Drover's Woods subdivisions had variable nitrate, chloride, and conductivity levels. For example, nitrate-nitrogen concentrations in these wells ranged over two orders of magnitude (0.2 mg/L to 25.6 mg/L). These bedrock wells have long open intervals and samples from these wells represent an "average" groundwater chemistry over that interval. However, the homes were far enough apart that the wells likely sampled water originating from distinct source areas with varying agricultural loading rates.

Samples collected from residential wells within Savannah Valley and Drovers Woods subdivisions showed less chemical variability. The wells within each of these subdivisions are close together and probably sampled water originating from a common source area. Nitrate-nitrogen concentrations were consistently between 2.0 and 6.5 mg/L in Savannah Valley wells and between 4.0 and 9.0 mg/L in Drovers Woods wells. However, there were two notable exceptions caused by differences in well construction.

Well WS-3 at the Savannah Valley site was cased just into the St. Peter sandstone unit, about 36 ft below land surface. Caliper logs suggest this uppermost unit is highly fractured, and it was difficult to lower a pump down this well due to partial collapse of the well bore. Elevated nitrate-nitrogen and chloride levels in this well suggest that preferential contaminant transport may be occurring in the upper bedrock fractures. Well RW-01 is located in Drovers Woods subdivision. It is cased 208 ft below ground surface, compared to the 40 to 60 ft of casing in the other bedrock wells. This well had undetectable nitrate-nitrogen and by far the lowest chloride concentration. These data suggest that even if groundwater chemistry beneath a rural subdivision has a uniform vertical profile across the site, differences in well construction can result in significant variations in water quality among private wells.

Nitrate Source Identification Using Nitrate-nitrogen Isotopes

Nitrate is a key water-quality parameter in this study because it is the most widespread contaminant in Wisconsin and one of the principal contaminants in domestic wastewater. However, because previous agricultural practices at this site have resulted in high background nitrate concentrations, it would be useful if nitrate derived from agricultural sources and could be differentiated from nitrogen derived from residential sources. Nitrogen isotope analyses have been used in many studies as a tool for identifying nitrate sources. The basis for this method is that nitrate derived from different sources will have different $^{15}N/^{14}N$ ratios, which are reported as $\delta^{15}N$ in units of "per mil" ($^0/_{00}$). Typical $\delta^{15}N$ values for human and animal waste nitrate and commercial fertilizers are +10 to +20 $^0/_{00}$ and –2 to +4 $^0/_{00}$, respectively (Aravena et al., 1993). Aravena et al. (1993) used nitrogen isotope analyses to successfully delineate a septic plume in an area with high background nitrate concentrations. In that study, $\delta^{15}N$ values within the septic plume (+8.1 to +13.9$^0/_{00}$) were much higher than those outside the plume (+3.4 to +6.2$^0/_{00}$).

Groundwater nitrate beneath the Savannah Valley subdivision site appears to have originated from both synthetic and organic fertilizers (such as manure), as the measured $\delta^{15}N$ values fall between the typical values for the two sources. The $\delta^{15}N$ values of nitrate from the seven wells ranged from +4.2 to +8.9 $^0/_{00}$, with a mean of +5.6 ± 1.7 $^0/_{00}$. However, the four wells with high nitrate concentrations (>10 mg/L as N) had the lowest $\delta^{15}N$ values, ranging from +4.2 to +5.2 $^0/_{00}$. This suggests that the primary source for the highest nitrate concentrations was synthetic fertilizer and not animal waste. The background $\delta^{15}N$ values measured in this study were lower than those measured in the septic plume by Aravena et al. (1993). Therefore, further nitrogen isotope analyses should be useful in identifying any future nitrate contamination from on-site wastewater treatment systems once homes are constructed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

For this study we installed monitoring equipment and acquired nearly two years of groundwater monitoring data prior to the construction of new homes at a rural subdivision site in south-central Wisconsin. The most important finding is the high variability - in both space and time - of predevelopment groundwater quality across this relatively small (78 acre) site. Concentrations of chemical parameters just below the water table exceeded drinking water standards for nitrate and atrazine in some wells and showed evidence of land-use impacts (agricultural use and highway salting) in many wells. Concentrations in deeper bedrock wells, although lower and less variable, also showed evidence of impacts from land use. Temporal variability is primarily caused by recharge patterns, because infiltrating precipitation and snowmelt enter the upper aquifer and can either dilute existing concentrations or bring in additional contaminants, depending on local conditions at the surface. Spatial variability is caused by aquifer heterogeneities, nonuniform agricultural loading patterns, and runoff of agricultural chemicals to topographically low points in the landscape. Groundwater quality is much more variable near the water table than deeper in the aquifer; samples collected from bedrock wells are much more consistent. Well construction, particularly casing depth, apparently controls chemical variability in these wells.

Groundwater at the Savannah Valley site appears to be very vulnerable to contamination from surface and near-surface sources. Groundwater flow at the site is relatively rapid, with estimated horizontal velocities on the order of 1 to 2 feet/day. Vertical groundwater movement is downward, with downward velocities on the order of 0.1 to 0.5 feet/day. Consequently, this site offers an excellent location to evaluate the effects of subdivision development on groundwater because potential impacts at the land surface should appear in groundwater within a few months or years.

The site characterization stage of this project has made it possible to predict the conditions and locations where groundwater will be particularly vulnerable to contamination from on-site wastewater-treatment systems. Wastewater will likely reach the water table more quickly and in higher concentrations in areas where the unsaturated zone is thin and consists of coarse, unlithified sediments. Although focused recharge in topographic lows may dilute wastewater in those areas, contaminants may be transported more quickly to the water table before adequate degradation can occur in the unsaturated zone. Contaminant concentrations across the site will likely be highest during drier seasons and years; decreased precipitation will limit dilution in the aquifer. Therefore, installing additional wells and collecting groundwater samples from the most vulnerable areas of the site during the driest times of the year would provide a "worst-case scenario" for groundwater quality beneath the subdivision.

Recommendations

The ultimate goal of this project was to identify the effects on groundwater, if any, of replacing agricultural land with an unsewered residential subdivision. The results obtained in the first stage of this study have several implications for the future success of this project.

1. Groundwater monitoring should continue at the Savannah Valley site as the subdivision is developed and septic systems come into use. The background data collected prior to development provides a good benchmark against which to compare future impacts from land-use change.

2. It is essential to distinguish impacts on groundwater chemistry due to land-use change from impacts related to natural or preexisting groundwater variability. Background monitoring requires adequately characterizing spatial and temporal variability in groundwater chemistry using a dense monitoring well network with frequent sampling intervals.

3. Groundwater monitoring at subdivisions should include shallow monitoring wells with short screens if the contaminants of interest are loaded at the ground surface or in the unsaturated zone. Contaminants applied above the water table will reach shallow wells more quickly and in higher concentrations than deeper water-supply wells. Wells with long open intervals monitor the "average" groundwater chemistry over long vertical intervals and might not detect small-scale changes in contaminant concentrations.

4. Identifying changes in groundwater chemistry due to land-use change can be difficult if similar contaminants are associated with both the new and former land use. Two of the principal contaminants in wastewater (chloride and nitrate) were already present in groundwater beneath the Savannah Valley site due to previous agricultural activity. In this case, it may be necessary to consider other contaminants or tracer methods that can differentiate between contaminant sources.

5. It is important to consider how subdivision construction may affect the temporal and spatial variability in groundwater chemistry observed prior to development. Stormwater-management practices may alter the timing or location of recharge and its ability to dilute the upper aquifer. These practices, along with grading and landscaping, will affect surface topography and runoff patterns at the site. Local loading patterns will change as continuous septic system point sources replace a seasonal, nonpoint agricultural source.

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APPENDIX A: Awards, Publications, Reports, Patents, and Presentations

Publications

Wilcox, J.D. 2003. Variability of groundwater chemistry in an agricultural setting and implications for assessing impacts of land use change. University of Wisconsin-Madison. M.S. Thesis. 121 p.

Presentations

Wilcox, J.D., K.R. Bradbury, J.M. Bahr, and C.L. Thomas. 2003. Variability of groundwater quality beneath an unsewered rural subdivision. Geological Society of America Abstracts with Programs (*November 2003)*.

Wilcox, J.D., J.M. Bahr, K.R. Bradbury, and C.L. Thomas. 2003. Variability in groundwater chemistry beneath agricultural and rural residential land uses. Wisconsin Ground Water Association Annual Conference Program.

Wilcox, J.D., C.L. Thomas, K.R. Bradbury, and J.M. Bahr. 2003. Spatial and temporal variability of groundwater chemistry beneath agricultural land: Implications for assessing environmental impacts of a new unsewered subdivision. American Water Resources Association – Wisconsin Section 27th Annual Meeting Program and Abstracts.

Awards

Jeff Wilcox: Best graduate student oral presentation, 2003 Wisconsin Ground Water Association Annual Conference.

Jeff Wilcox: Best student poster presentation, 2003 American Water Resources Association-Wisconsin Section Annual Meeting.