An Analysis of Arsenic Replacement Wells to Determine Validity of Current Department of Natural Resources Guidance

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Project Summary

Title: An Analysis of Arsenic Replacement Wells to Determine Validity of Current Department of Natural Resources Guidance

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Background/Need: The occurrence of arsenic in groundwater in parts of Northeast Wisconsin was first identified in 1987 during a routine feasibility study for a proposed landfill location in the town of Vinland, Winnebago County, and has been an ongoing problem since that discovery. Drinking water wells near the proposed landfill site were sampled for background parameters to develop baseline data on groundwater quality in the area. When many of the samples were found to have higher arsenic levels than would be expected for background parameters, an investigation ensued and it was determined that the arsenic in this area is naturally occurring. Since that time, several studies have been undertaken to determine the extent of the problem. Some of these studies have focused on providing solutions to property owners who rely on private wells for drinking water and well drillers who need to be able to advise their customers on the best well drilling techniques to prevent or dramatically reduce the amount of arsenic in potable wells. Based on these studies, the Wisconsin Department of Natural Resources (WDNR) delineated an Arsenic Advisory Area (AAA) and provided recommendations for drilling wells in this area. To determine if the WDNR's recommendations were having the intended result of eliminating or dramatically reducing the amount of arsenic in potable wells, it was necessary to conduct arsenic sampling of wells in the AAA that were constructed according to these recommendations and compare these results to other wells in this area that were not constructed with any precautionary measures. This study attempted to test the validity of the WDNR's recommendations, and ultimately to advise the WDNR if the guidance should become mandatory or if modifications to the guidance are warranted.

Objectives: There were four objectives to this study:

1. Determine if the current well construction guidance is eliminating or reducing naturally occurring arsenic in potable wells.
2. Observe the effect of seasonal changes on arsenic levels.
3. Examine if the degree of arsenic contamination increases over time.
4. Discover which physical factors are potentially contributing to the "failure" of reconstructed or replacement wells.

Methods: Letters were sent to select potable well owners located in the area of interest asking them to participate in this study. A total of 64 wells were included. Drinking water samples were collected from selected wells during five separate sampling events over a period of 18 months, from November 2000 to April 2001. Samples were laboratory analyzed for arsenic, and some sampling events included analysis for iron, conductivity and pH.

Results/Discussion: While the issue is complex and there are many variables, in general, the sampling results did not provide strong evidence for the WDNR to continue their current guidance of recommending that drillers case wells a minimum of 80 feet into the St. Peter Sandstone (StP).

Recommendations: Our recommendation is that well drillers go beyond the "80 feet" guidance and follow the WDNR's most recent (2004) recommendation to drill wells that avoid drawing water from the StP. In addition, we recommend that sampling be performed on a regular basis and that local units of government educate their residents in the Arsenic Advisory Area of the health effects of arsenic and provide a sustainable methodology for sampling (e.g., initiate annual or semi-annual Town Based Sampling events).

Related Publications: Weissbach, A, Heinen, E., and Lauridsen, K. A study of well construction guidance for arsenic contamination in Northeast Wisconsin. WDNR, December, 1998.

Key Words: Arsenic, Groundwater, Potable Wells, St. Peter Sandstone, Northeast Wisconsin

Funding: Wisconsin Department of Natural Resources

Final Report: A final report containing more detailed information on this project is available for loan at the Water Resources Institute Library, University of Wisconsin - Madison, 1975 Willow Drive, Madison, Wisconsin 53706 (608) 262-3069.

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1. Introduction

In 1987, naturally occurring arsenic was discovered during a landfill feasibility study in the town of Vinland, Winnebago County. Since that discovery, it has been known that groundwater in parts of east central Wisconsin can contain levels of naturally occurring arsenic in amounts that exceeded the previous Maximum Contaminant Level (MCL) allowed under the State of Wisconsin's Pure Drinking Water Act of 50 micrograms per liter (ppb). Although this area of Wisconsin has recorded some of the highest arsenic results in the world, in some cases greater than 12,000 ppb, the state is not alone in dealing with this problem. Groundwater contaminated with naturally occurring arsenic has been found in many other parts of the United States and increasingly around the world.

Since this arsenic problem was discovered, the Wisconsin Department of Natural Resources (WDNR) has been studying it and developing guidance to deal with the problem in both private and public wells. This study addresses and analyzes guidance that was developed in 1998 for well drillers drilling private wells in areas known to have naturally occurring arsenic. This guidance, which can be found in Appendix B, recommended that drillers should either avoid the St. Peter Sandstone (StP) by drawing water from the upper Galena Platteville (GP) limestone or the lower Prairie du Chien (PdC), or, if they must draw from the StP, to case off at least the top 80 feet of it.

The Safe Drinking Water Act standard for arsenic is established by the United States Environmental Protection Agency (EPA). On October 23, 2001 (during the course of this study) EPA announced that the standard or Maximum Contaminant Level (MCL) would be lowered to 10 ppb. This standard is developed for public water supplies, which must be in compliance by January 23, 2006. The State of Wisconsin has also adopted this standard under ch. NR 140, with an effective date of March 1, 2004. The State of Wisconsin does not enforce this standard on private water systems; rather, it is used as a guideline for homeowners to determine if their drinking water is safe. Although it is not technically enforced on private wells, if private well owners do not have viable well construction or treatment options for dealing with this problem, some could face significant health implications and property values could potentially be affected.

1.1 Health Impacts

Several recent studies have been conducted that link long-term exposure to arsenic contaminated drinking water to several types of cancer, including skin, bladder, lungs, liver, and prostate (U.S.

Environmental Protection Agency, 1998; World Health Organization, 1996.) Other health effects related to arsenic in ground water include cardiovascular, pulmonary, immunological, neurological, and endocrine disruptions. The Wisconsin Department of Health and Family Services (DHFS) published a study, *Health Effects of Arsenic Contaminated Drinking Water* (Knobeloch, 2002), that looked at the health effects of families in Winnebago and Outagamie Counties who had been consuming arsenic-contaminated water. The study found that people over the age of 50 who had consumed water with an arsenic level greater than 5 ppb for 10 or more years were more likely to have been diagnosed with skin cancer. Cigarette smokers who consumed arsenic tainted water were found to be at a greater risk than nonsmokers of developing skin cancer. This study did not find a correlation between drinking arsenic contaminated water and other types of cancer. However, the authors did state that "these results must be interpreted cautiously due to the small number of cases reported by study participants."

1.2 Geology of the Study Area

Various studies performed in Northeast Wisconsin indicate that most of the high arsenic levels in private wells are caused by chemical reactions occurring naturally in or near the **St. Peter Sandstone (StP)** aquifer. A mineralized layer containing high levels of pyrite (FeS_2) with arsenic attached to its crystal structure is present primarily at the top of the StP formation. Where the StP is absent, this mineralized zone may be present at the base of the **Galena-Platteville (GP)** formation and/or in the upper **Prairie du Chien (PdC)** formation. It is postulated that this mineralized zone originated from metallic brines that were formed during sedimentation of the Michigan Basin during the latter part of the Paleozoic Era. These hydrothermal brines flowed upslope through most of the formations and mineralized primarily at the contact between the StP and GP formations. This created the arsenic bearing zones called the **sulfide cement horizon (SCH)** (Simo and Freiberg, 1996). Generally these deposits can be identified visually as a black or dark gray layer at the contact, or as shiny pyrite/marcasite minerals. The theory is that when oxygen is introduced into the arsenic bearing mineralized zone, pyrite is oxidized and the arsenic is released to groundwater (Burkel,1993; Pelczar, 1996; Schreiber et al., 2003).

A second release mechanism involves reduction or replacement reactions with arsenic that is adsorbed to iron oxy-hydroxides (FeOOH). Since the arsenic-bearing pyrites have been in place for approximately 200 million years, oxidation has likely taken place on numerous occasions. The arsenic release during the oxidative events would either reform into sulfide minerals under reducing conditions or sorb to iron oxides (Schreiber et al., 2000). While this mechanism is less likely to cause high levels of arsenic contamination it can easily lead to levels exceeding the recently passed standard of 10 ppb.

It is believed that there are generally three ways in which released arsenic can get into well water. These are represented in Figure 1, (prepared by WDNR Hydrogeologist Dave Johnson). Scenario 1 is by far the most common and direct method, particularly in older shorter-cased wells. We now know that these arsenic-containing minerals can be found not only in the StP, but also in lower formations, such as the PdC and even the Cambrian formation (Burkel, 1993; Brown and Maass, 1992; plus personal communication with Dave Johnson, WDNR Hydrogeologist).

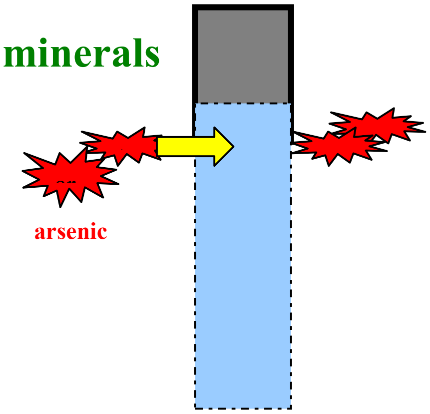
1.3 Previous Research

To understand the extent of this problem in Northeast Wisconsin and attempt to provide solutions to manage it in the most cost-effective manner, several studies relating to arsenic in potable wells have been conducted over the years. One of the initial studies involved sampling 1037 wells in Outagamie and Winnebago Counties (Burkel, 1993). This study identified 37 wells (3.6%) that exceeded the existing drinking water standard of 50 ppb and 185 wells (17.8%) that had arsenic levels exceeding 10 ppb. This research indicated that there appears to be higher levels of arsenic contamination in the area that is closest to the sub-crop of the StP. Based on this finding, the WDNR was able to designate an Arsenic Advisory Area (AAA) that has boundaries extending five miles on either side of the sub-crop of the SS and includes most of Outagamie and Winnebago Counties (Appendix A).

As stated in the Introduction, the WDNR also issued the ***Well Driller Guidance for Well Construction in Areas with Naturally Occurring Arsenic Water Quality Problems*** in February of 1998 (Appendix B). The well driller guidance recommended that new potable wells in the AAA should be constructed to draw water from either the upper GP or lower PdC limestone layers, rather than the StP aquifer. Additionally, the guidance recommended that "if it is necessary to penetrate the StP, a minimum of 80 feet of the StP should be cased in an effort to "seal off" the arsenic bearing zone." While drillers were encouraged to terminate the lower bore hole in the GP and not "disturb" the StP, opportunities for deriving enough water from the GP were limited due to drawdown of the water table.

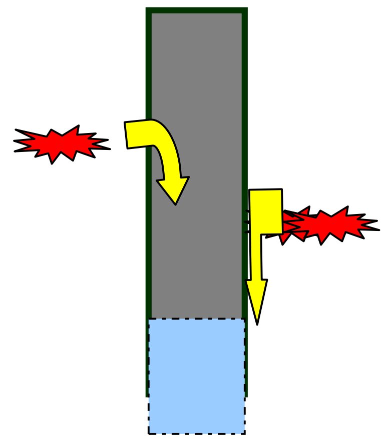
Figure 1: <u>Modes of Arsenic Release Into Well Water</u>

1) Directly drawing from zone with arsenic bearing minerals

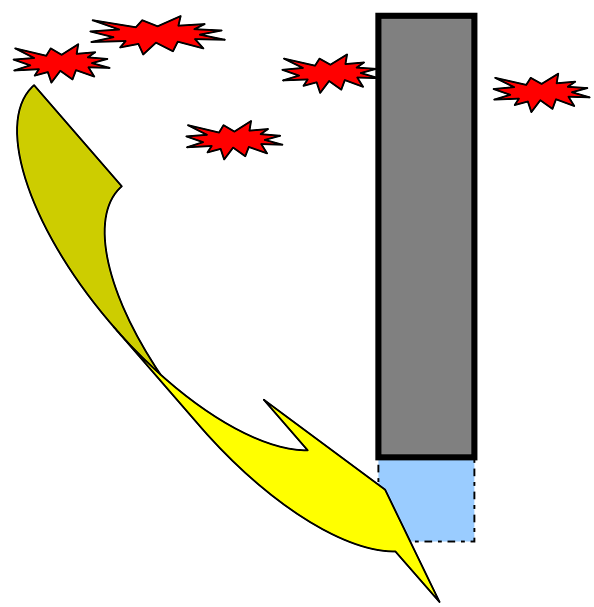


Solutions:
Case deeper
No air rotary drilling
Limited use of hypochlorite

2) Grout and casing compromised by acid conditions



Solutions:
Enhanced grouts
Protect steel casing
Alternative casing materials



3) Migration of arsenic

Solutions:
Case deeper (e.g., through the StP)
Water conservation

One of the first studies to test the effectiveness of this guidance was conducted by Pelczar (1996), who sampled six drinking water wells and three monitoring wells. The results, although limited by the small number of wells, suggests that replacing a well with enough casing to seal off the arsenic-bearing stratum was effective in reducing arsenic concentrations.

In 1998, WDNR staff completed a research project called *A Study of Well Construction Guidance for Arsenic Contamination in Northeast Wisconsin* (Weissbach et al. 1998). The primary objective of this study was to determine if the WDNR's current Well Driller Guidance was having the desired result of reducing the level of arsenic in wells in the AAA (similar objective to this study). The study found that the current guidance "appears to provide adequate protection for wells constructed in the AAA." The authors did note that wells that were constructed properly the first time tended to have a better success rate than replacement wells. Another objective was to determine if arsenic concentrations increase over time. The authors stated that the 74 wells that they tested did not show any "appreciable rise in arsenic concentrations over time." They also noted that, given the variability and complexity of the problem and the limited sample size, more study is needed to fully understand this issue since "WDNR staff receive several calls per month relating to newly discovered arsenic in previously uncontaminated wells."

One recommendation of this study was that "WDNR Well Driller Guidance for well construction in areas with naturally occurring arsenic water quality problems should be amended to require at least 40 feet of casing, cement-grouted in place through the top of the StP if the StP is penetrated." Another recommendation was to reduce the AAA boundaries to include only Algoma Township in Winnebago County and Osborn Township in Outagamie County, but within this area the well driller guidance should be a requirement rather than a recommendation. The boundaries of the AAA were not decreased; however, effective April 22, 2002, the WDNR made it mandatory (rather than just advisory) for portions of the towns of Algoma and Omro, both in Winnebago County, to follow the guidelines established for the "Special Well Casing Pipe Depth Area" (Appendix C). These guidelines provide two options for drilling wells, both of which require the well to be constructed to draw water from an aquifer other than the StP to minimize the risk of naturally occurring arsenic in these wells.

In the spring of 1999, WDNR staff conducted follow-up sampling on 11 replacement wells, the majority located within the arsenic-rich town of Algoma. These wells were drilled under the WI Well Compensation Program, and since they received grant money to replace existing wells, all wells were required to be constructed according to the WDNR's guidance for construction of arsenic wells; i.e.

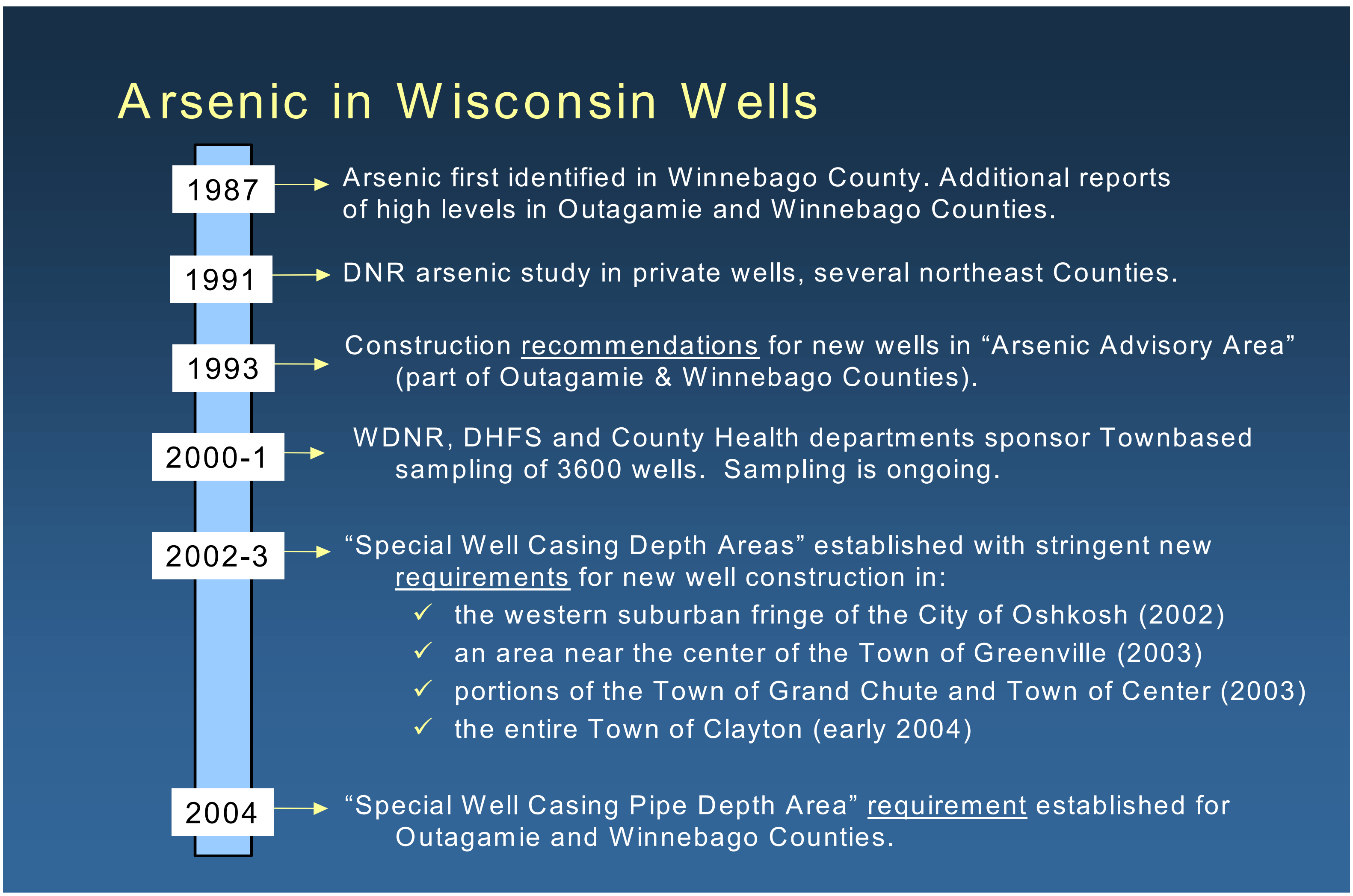
with 80 feet of casing into the StP. Immediately after construction, all of the wells were tested for arsenic and all showed concentrations below the Safe Drinking Water Act Standard, which at the time was 50 ppb. The follow-up testing of these wells, which was conducted a year or two later, identified two wells that significantly exceeded the standard, with levels increasing from less than 2 ppb to an average of 200 ppb within 7 months. In addition, 2 more wells in Outagamie County appeared to have "failed" by exceeding the standard. The results of this follow-up testing, combined with the recommendations from the 1998 study, prompted the authors to apply for a grant to conduct this current study.

As awareness of the problem increased, many towns in Winnebago and Outagamie Counties, in cooperation with their local health departments, WDNR, DHFS, and the Wisconsin Department of Commerce (DCOM), offered residents the opportunity to test their wells for arsenic through town-based sampling events. Generally these events, which continue today and are conducted annually in some towns, provide a lower-cost and more convenient option for people to have their wells tested for arsenic. It also provides the WDNR and health departments the opportunity to provide education to participants on the health effects of arsenic.

When the town of Algoma conducted its first town-based sampling event in 2000, there were 762 participants and 266 (34.9%) had arsenic levels greater than the "new" standard of 10 ppb. Of these 266 wells, 62 exceeded 50 ppb. The town of Algoma was, and still is, experiencing rapid urban-sprawl-type development with private water wells and it is believed that this development exacerbates the arsenic problem by introducing oxygen into the aquifer during the drilling process. Oxygen may be introduced into the aquifer initially via air rotary well drilling methods and/or the operation of the well itself (pumping levels, heavy chlorination, etc), and also via the depression of the water table. The oxygen then activates the oxidation process, which releases the arsenic into the groundwater and this reaction appears to sustain itself (Weissbach et al., 1998). Despite ongoing studies, it is not yet entirely clear how and to what degree this reaction migrates vertically and horizontally once it has begun (Schreiber et al., 1999), which means that arsenic levels in wells that were initially below the standard sometimes increase over time. This reaction could also have an effect on wells that are in close proximity to one another. Much of the development in the town of Algoma has been occurring on small lots with some wells being as little as 25 feet apart.

As the WDNR became aware of several wells that initially tested at acceptable levels for arsenic and then appeared to increase over a time period ranging from several months to several years, concern about the scientific validity of WDNR's well construction guidance grew. This discovery made it evident that additional research on well construction techniques would be necessary to attempt to determine why some wells appeared to fail after following the WDNR's guidance. As a result, the WDNR decided to conduct a follow up research study that would include re-sampling wells that had previously participated in the *Study of Well Construction Guidance for Arsenic Contamination in Northeast Wisconsin,* and adding additional wells (prompting this study). Since it had become apparent that the town of Algoma was facing greater problems, the study focused on wells in that area. Figure 2 shows a diagramatic depiction of this evolution.

Figure 2: Chronology of Arsenic Research and Guidance



2. Objectives

Four objectives were identified in this study.

2.1 Is Current Guidance Working?

The primary objective of this study was to determine if the current well construction guidance – case 80 feet into the StP - is consistently having the intended result of permanently eliminating, or at least dramatically reducing, naturally-occurring arsenic in drinking water. If the findings showed that the guidance is valid, this study could help the WDNR decide if the special well casing **advisory** should be elevated to a well casing **requirement**. If it appears to be invalid, this research can help the WDNR make modifications to the guidelines. As previously mentioned, the special well casing was in fact made a requirement during the course of this study, and as of April 2002, this became a requirement for portions of Algoma and Omro Townships in Winnebago County. In addition, just prior to this report going to press, in October of 2004, a special casing requirement was imposed upon all of Outagamie and Winnebago Counties.

2.2 Are There Seasonal Variations?

A second objective was to determine if there were seasonal variations in arsenic levels. *A Study of Well Construction Guidance for Arsenic Contamination in Northeast Wisconsin* (Weissbach *et al.*, 1998) did not find that seasonal variations occur, but there were two wells that each experienced one unexplained significant increase in arsenic levels. This finding led the authors to caution that "seasonal variations of arsenic levels in drinking water are *possible*." It has also been noted from other data that some seasonal trends may exist, with higher results in the fall than other months of the years. Therefore, this study also attempted to assess seasonal variations. To accomplish this, sampling was conducted during each of the four seasons.

2.3 Are Arsenic Levels Increasing Over Time?

A third objective of this study was to determine if arsenic levels in individual wells increase over time. The results of the 1998 Weissbach *et al* study "did not show any appreciable rise in arsenic concentrations over time." However, many of the wells that were sampled during that study had been drilled or reconstructed between January 1, 1994 and December 31, 1995 with sampling events occurring between April of 1997 and January of 1998. Consequently, it is possible that these wells were not in existence long enough for the chemical reaction to occur. This, combined with the fact that the WDNR was seeing well compensation program wells that "failed," further supported the need for follow-up testing.

2.4 What Causes Wells to 'Fail'?

A final objective was to determine what factors are potentially contributing to the 'failure' of some wells that had been constructed according to the WDNR's guidance. A number of wells showed increasing arsenic levels despite the fact that the driller had followed the WDNR's recommendations. Throughout this document, these wells will be referred to as 'failed' wells. Some theories as to why this occurred were that there were problems with the grouting in the annular spaces, the well casing had deteriorated from low-pH acidic groundwater, or contamination from a neighboring well had migrated vertically and horizontally. There was a very limited amount of funding available for this testing, so only basic pressure testing, 'free-drain' testing, and down-hole video analysis were conducted on 3 failed wells.

3. Methodology

This section describes the methodology used to accomplish the objectives of the study.

3.1 Water Well Sampling

To determine the validity of the well construction guidance, wells were selected according to whether or not they followed the guidance, and then a comparative analysis was conducted. The study area's primary focus was the town of Algoma, a town just west of the city of Oshkosh in Winnebago County. This area was known to have many homes affected with high arsenic levels, and it was decided that analyzing wells in a single geographical area had merit since differences in contaminant levels would more likely be due to well construction techniques rather than to geological differences. However, this is complex, as it is known that geologic variation and arsenic levels are known to occur from literally one side of the street to the other.

The second objective of this study - to determine if the variations in arsenic levels correspond to seasonal changes in the water table during periods of draw down or aquifer recharge – was carried out by collecting samples during each season over a two-year period to determine if the level of arsenic fluctuated throughout the year.

The third objective was to examine if the level of arsenic increases over time. There have been several cases where the arsenic contamination level increased in a well that formerly had low levels of arsenic. Many have speculated that this could be due to casing failure as the well ages. To test this theory and gain a better understanding of this observed phenomenon, historical data from wells in the previous 1998 Weissbach et al. study on well construction guidance were compared with the analytical data from this study.

3.1.1 Well Selection

The initial plan was to include 75 wells in the study that would be divided into two groups: those that were not constructed according to the most current WDNR well driller's guidance, and those that were.

Wells that were constructed according to guidance were to be grouped into the following categories:

- **25 that were replaced or reconstructed with the recommended 80 feet of additional casing beyond the top of the StP.**
- **10 original wells that installed the recommended 80 feet of additional casing beyond the top of the StP.**
- **5 wells that were constructed according to the recommendation to terminate the well prior to drilling into the StP; i.e., wells drawing water from the GP limestone.**

Wells that were not constructed according to guidance were to be grouped into the following categories:

- **15 wells constructed with minimum casing (These wells were constructed according to the minimum requirements of ch. NR 812, Wis. Adm. Code. Many have 42 feet of casing from the top of the well and are drawing water directly from the StP.)**
- **10 constructed with 5-40 feet of casing beyond the top of the StP**
- **10 constructed with 41-79 feet of casing beyond the top of the StP**

The purpose of differentiating among the wells not constructed according to current guidance – i.e., less than 80 feet of casing - was to determine the validity of recommending 80 feet, and, given the lack of knowledge regarding vertical migration, determine if less casing would yield the same results. There was an obvious economic reason for this evaluation. At the time steel casing cost approximately $5.50 per foot and if it were determined that wells with shorter casing would effectively reduce or eliminate the problem, drilling costs would be reduced considerably, particularly if compared with casing through the entire StP formation. We were also interested in comparing the success rate of wells with greater than 80 feet of casing with those less than 80 feet to determine if casing depth alone could affect arsenic concentrations or if other variables masked any differences.

The majority of wells chosen for the study had either participated in the earlier WDNR study on well construction guidance or the well had been constructed through the well compensation program. Early in the selection process it became evident that there would not be enough wells included in the study if the selection was based on these criteria alone, so a file search of well logs was conducted to find more suitable candidates. The newly selected wells would need to fit into one of the above categories and preferentially be located in the town of Algoma.

Prior to making a final selection, all well logs were reviewed to determine if the geology surrounding the well was appropriate for the study. Any wells that were not included in the previous study on well construction guidance or wells that had not participated in the Well Compensation Program had to be researched to verify, and in some cases to find, the correct location of the well. The Wisconsin Unique Well Number (WUWN) also had to be confirmed to ensure that the well geology was accurate.

In October of 2000, when the final wells were selected and all well locations were confirmed, 80 letters were mailed to homeowners that were chosen to participate in the study (Appendix D). The letters briefly explained that the purpose of the study was to attempt to make determinations about what type of well construction is most effective in reducing or eliminating the presence of arsenic in well water. Also included was a questionnaire, which helped to select the best outside location to collect a sample, since the sampling point should be the one closest to the well and free of treatment devices. The response form also asked homeowners for information about water treatment devices that were installed for their water supply, and any arsenic results that they had. The arsenic results homeowners included were usually from memory, with no accompanying laboratory results.

There was great interest in the study, with 58 responses, a response rate of 73%, which confirmed that this is a problem of great concern to these residents. In fact, three homeowners, upon hearing of the study from neighbors, requested that they be allowed to participate.

After all interested parties returned their questionnaires it became apparent that there would be a limited sample of wells in some of the categories. Unfortunately, this would make it difficult to draw conclusions about these types of wells, so we decided to simply divide the wells according to those that had followed the guidance and those that had not. The definition of wells that followed guidance became ones that had installed *nearly* 80 feet of casing or more into the StP. The reason for this change was that well log records are not always completely accurate in recording the geology; it is up to the well driller to decide where the StP begins and where it ends and at times this is an estimate. Three wells were moved into the category of wells that followed guidance that otherwise would have been included in the category of wells with 40 – 79 feet of casing beyond the StP.

After the first round of sampling, two property owners withdrew from the study, likely due to privacy concerns and potential resale issues when the information would become public. There were two other wells that were added later during the study. One was not identified prior to the start of the study and the other one was a replacement well constructed in January of 2001, after the study began. This well was of great interest, because of the extraordinarily high levels of arsenic and iron. The original well on this property (WUWN IG 602) had arsenic levels as high as 3800 ppb. There were also two wells that were replaced during the course of the study.

Ultimately, we ended up with a total of 64 wells on 62 properties (Table I). The division of wells that completed the study is as follows:

- **23 wells that were not constructed according to guidance**
- **41 wells that were constructed according to guidance**

Of the wells constructed according to guidance, 12 were **original wells** on the property and 2 of these wells were shallow wells drawing from the GP limestone. There were 20 **replacement wells** that had been redrilled at different locations on a property where a previous well had become contaminated with arsenic. There were also 9 reconstructed wells included in the study. A **reconstructed well** involved deepening the borehole and installing a liner in the original well. The liner is then sealed with grout and a packer holds the grout in place.

Appendix E contains 5 maps showing sampling locations and results (within a range) for wells sampled within the town of Algoma. Sampling points in other towns are not represented on a map, because there were a small number of sampling points spread out over a relatively large geographical area.

Table I: Well selection by Township and County

Well Location by Township & County	Wells Not Constructed According to Guidance	Original Wells Constructed According to Guidance	Reconstructed Wells Constructed According to Guidance	Replacement Wells Constructed According to Guidance	Total Number of Wells in Township
Algoma (W)	17	12	8	11	48
Angelica (S)	0	0	0	2	2
Center (O)	0	0	0	1	1
Clayton (W)	2	0	0	2	4
Grand Chute (O)	0	0	0	1	1
Osborn (O)	2	0	1	1	4
Seymour (O)	0	0	0	1	1
Utica (W)	1	0	0	0	1
Vinland (W)	1	0	0	0	1
Winchester (W)	0	0	0	1	1
Total Wells in Category	23	12	9	20	

O= Outagamie County

S= Shawano County

W= Winnebago County

3.1.2 Potable Well Sampling

Prior to collection of the first round of samples, each homeowner was contacted by phone to confirm that the well selected corresponded with the address. The homeowner was asked if it would be possible to sample from an outside collection point to eliminate the need for their presence at the time of sample collection. The majority of the homeowners had an untreated outside faucet available that could be used for collecting the sample and it was agreed that the homeowner would be notified prior to each sampling event so they could ensure that the outside faucets were accessible on the collection date. A few participants either were not sure about their plumbing, did not have an untreated faucet available, or preferred that the sample be collected when they could be present. In those situations, an appointment was made with the homeowner and the sample was collected from inside at the pressure tank.

The first round of sampling was conducted in November 2000 and samples were collected from 59 of the participant's wells. A water sample was drawn from each well and sent to the State Lab of Hygiene (SLOH) to be analyzed for arsenic and iron. A comparison of the analytical results from this first sampling event with historical test results (where available) revealed that 5 wells had no significant change in arsenic levels. Based on this apparent stability, it was decided that those five wells would not be sampled in the next round.

The second round of sampling took place in April 2001 and 57 samples were collected. This round included the 3 additional wells that were added after the initial sampling event occurred. The samples were again sent to the SLOH to be analyzed for arsenic. Field tests were also conducted on each of the samples for pH and conductivity.

The third and fourth rounds of sampling, which occurred in August and December 2001, consisted of collecting 57 drinking water samples that were sent to the SLOH to be analyzed for arsenic only. No field tests were conducted.

In March and April of 2002, the final sampling event occurred and water samples were collected from 61 out of the 62 study participant's wells. One property (WUWN FP 851) was in the process of being sold and the property owner did not want the final sample to be collected, an example of the social and economic aspects of this issue. Samples were sent to the SLOH to be analyzed for arsenic only.

3.1.3 Sampling Protocol

The water samples to be analyzed at the laboratory were collected in the same manner during all five sampling events. The faucet from which the sample would be drawn was turned on and allowed to flow for 10-15 minutes or until the pump kicked on to assure the sample was drawn from the well as opposed to the pressure tank. After that period of time, the sample was collected in a 250 mL polyethylene bottle. The lab stated that arsenic samples and iron samples would not need to be preserved prior to reaching the lab nor would they have to be kept cold. Therefore, the samples were held until all collection was completed, at which time they were shipped to SLOH in Madison.

After receiving the results, homeowners were sent a copy of the lab data along with a letter explaining the results**.** When the standard exceeded 50 ppb, the homeowner also received a statement cautioning them about drinking the water and a list of Wisconsin Department of Commerce approved water treatment devices for the removal of arsenic from drinking water.

Field tests for pH and conductivity were conducted immediately after collecting the sample for laboratory analysis. Another 250 mL polyethylene bottle was filled with water from the same faucet from which the lab sample was drawn. This bottle was filled to the shoulder to allow ample space for the pH and conductivity probes to be inserted. The pH test was conducted with the Corning 105 Hand Held pH Meter. The conductivity test was conducted with the Orion Conductivity Meter Model #122.

3.2 Physical Testing of Failed Wells

To accomplish the final objective - to investigate possible reasons for the ‘failure’ of selected wells constructed according to guidance that initially were deemed successful but failed over time – basic physical testing was conducted on 3 wells.

Given budget and expertise constraints, the methodology for ‘physical’ testing was quite minimal, consisting basically of down hole video analysis, borehole flow meter analysis, and partial abandonment of a failed well followed by a ‘free-drain’ test to ascertain if the casing integrity was a possible reason for the well’s failure. These wells were located in the town of Algoma, Winnebago County, the town of Grand Chute, Outagamie County, and the town of Angelica, eastern Shawano County. This testing was accomplished through well drillers generally donating their time and equipment.

To test the theory that vertical and horizontal migration could be contributing to the failure of a previously safe well if a neighboring well underwent the oxidative reaction releasing arsenic into the aquifer, researchers analyzed data from two wells on the same property. Another hypothesis discovered and investigated during the course of this study was that arsenic could adhere to the inside of the plumbing and continue to release arsenic into the water system from the pipes after a new well is drilled.

For further details on the methods and results of the physical testing, see section 4 ,“Results and Discussion” and Appendix H.

3.3 Additional Well Evaluation

As the study progressed over multiple years, additional data was gathered from wells being drilled as the recommendations evolved. These wells were mostly replacement wells on properties with known arsenic problems or adjacent properties. The information on drilling method, amount of casing, grouting method and level of post construction disinfection were evaluated. This information was ultimately used to guide and support the Department's recommendations to expand the special casing requirements.

4. Results and Discussion

The arsenic concentrations in the wells tested in this study ranged from no detect (0) to 1100 ppb. The limit of detection (LOD) was 0.6 ppb, therefore, any wells recorded as 0 could have minimal traces of arsenic. The median arsenic concentration for all wells in the study was 12 ppb and the average concentration was 30 ppb. There were two wells, WUWNs MY 397 and PR 751, that had extremely high arsenic levels, which accounts for the large difference between the median level and the average.

The median value for wells in the town of Algoma was 12 ppb and the average was 25 ppb. Wells in the remaining study area had a median value of 11 ppb and an average of 51 ppb. The median value was 12 ppb for wells that were constructed according to the WDNR's guidance and those that were not. The average for wells that were constructed according to guidance was 28 ppb and the average for those that were not constructed according to guidance was 33 ppb.

Appendix F contains tables summarizing groundwater results for all sampling parameters, including a raw data table, wells constructed according to guidance, wells constructed with minimum casing, results for the town of Algoma, results for all remaining participating townships, and results for wells that were included in the 1998 Weissbach et al. study and this study. Wells are arranged in the tables by the amount of casing depth into the StP (see legend on tables) except for the raw data table for all wells sampled, which is arranged according to well type (original, reconstructed, replacement) and then construction date. The only other exception is on the table of results for remaining study area. On that table there are two properties, Elm Road and French Road, that had wells replaced during the course of the study. For each property, the two wells are kept together in the table.

4. 1 Arsenic Results Based on Well Construction

Due to the changing Drinking Water Standard, wells were categorized based on the results being less than 50 (the old standard) or less than 10 (the new standard). Since the standard was 50 ppb when the study began and when the original well drilling guidance went into effect, it was deemed necessary to determine how successful the wells would be under the previous standard of 50 ppb and the current standard of 10 ppb. The following tables compare the effectiveness of each type of well construction under each standard. These tables are categorized by maximum value; since this is a health issue, it made more sense to use maximum values rather than averages for this table.

Table II: Effectiveness of wells meeting standards based on well construction

Arsenic Level	**Wells Not Constructed According to Guidance**	**Wells Constructed According to Guidance**
<10 ppb	10 (43.5%)	18 (43.9%)
10 – 49 ppb	10 (43.5%)	20 (48.8%)
>50 ppb	3 (13%)	3 (7.3%)

Table II illustrates the effectiveness of wells based on whether or not the well was constructed according to guidance. There is essentially (statistically) no difference in the success rate of the wells meeting the current standard whether the guidance was followed or not (43.9% compared to 43.5% success rate, respectively). However, it should be noted that the wells that followed the guidance would have had a slightly better success rate if the standard had remained 50 ppb. Wells constructed according to guidance would have had a success rate of 92.7% compared to 87% for those that did not, indicating that even if the standard had remained at 50 ppb, the '80-foot' guidance would likely not have been adequate.

To determine if there is a difference between the success rates of wells that did follow guidance based on the type of well, the wells were further compared based on the three different types of wells that did follow guidance, as seen in Table III.

Original and replacement wells tended to have a greater success rate than reconstructed wells based on the current standard of 10 ppb. Since there are a limited number of wells in each category, it is difficult to know if they would continue to have a greater success rate over a larger sampling set. If the standard had remained 50 ppb, reconstructed and replacement wells would have had very similar success rates, 89% and 90%, respectively.

Table III: Success rates of wells meeting standards based on type of well

Arsenic Level	Original Well	Reconstructed Well	Replacement Well
<10 ppb	6 (50%)	2 (22%)	10 (50%)
10 – 49 ppb	6 (50%)	6 (67%)	8 (40%)
>50 ppb	0 (0%)	1 (11%)	2 (10%)

Table IV: Distribution of arsenic levels in wells based on location and well construction

	Town of Algoma		All Remaining Townships	
Arsenic Level	Wells Not Constructed According to Guidance	Wells Constructed According to Guidance	Wells Not Constructed According to Guidance	Wells Constructed According to Guidance
< 10 ppb	7	13	3	5
10 – 49 ppb	8	16	3	3
> 50 ppb	3	1	0	2

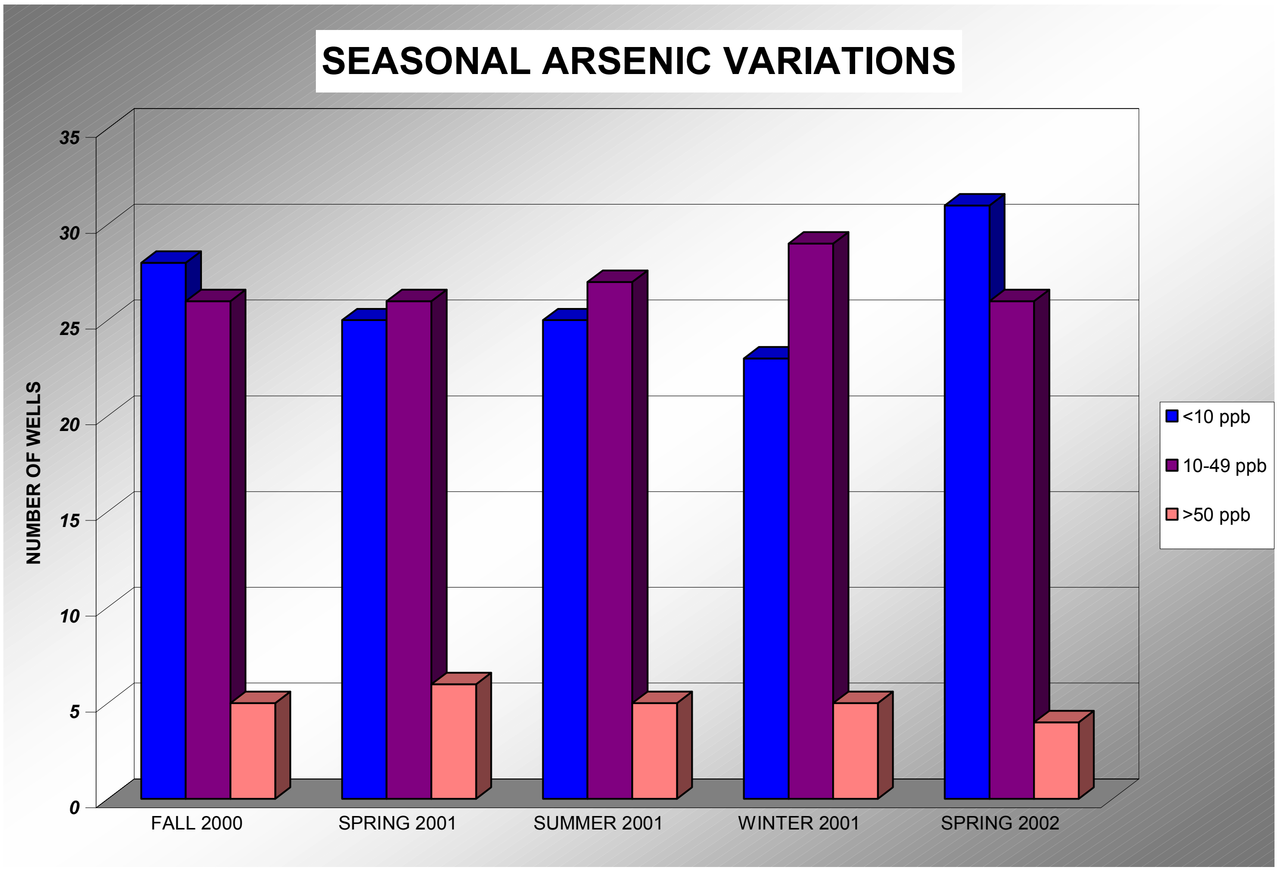
Table IV shows the distribution of wells in Algoma and all remaining townships grouped according to the highest arsenic concentration encountered for that well during this study. This is for illustrative purposes only to understand how the arsenic levels varied depending on location and construction technique. Since the wells were not randomly selected, but rather were selected based on meeting the study's criteria, the table is not intended to be used for comparative purposes of success rates based on location.

4.2 Seasonal Variation of Arsenic Level

Overall, there were minimal differences in the amount of arsenic in the wells from one season to another. In fact, only eight wells, all in the town of Algoma, fluctuated between categories, but there was not a trend to indicate that arsenic levels are consistently higher in any specific season.

Figure 3 illustrates the range of arsenic in the wells during each of the sampling events. Some wells that participated in the earlier Weissbach *et al* (1998) study were not sampled during Spring, Summer and Winter of 2001; these were dropped from this study because there were not any significant changes in the arsenic level over time nor had there been any seasonal variation in these wells during the earlier study. This accounts for the larger number of wells in the <10 ppb category during the Fall of 2000 and the Spring of 2002 sampling events.

Figure 3: Seasonal Variations of Arsenic Levels



4.3 Effect of Time on Arsenic Level

Wells sampled in this study did not show a significant change (increase) in arsenic concentrations over time. In order to expand the sample size and make the analyses more meaningful, sample data from the 1998 Weissbach *et al* study were included in this analysis. The 4 samples from the 1998 study were averaged and a standard deviation was applied, and the 5 samples from the 2002 study were also averaged and a standard deviation was applied. Table V shows that 5 of the wells (42%) decreased over time, 2 wells (17%) increased, and 5 wells (41%) did not change significantly enough to note as a change. Of the 5 wells that decreased, 2 had relatively significant decreases (35 and 30%), while the other three were quite small. Based on this information, it does not appear that there is a trend toward increasing over time, at least not amongst these wells that were included in this study. There are many variables related to changes in arsenic levels over time, so it is difficult to ascertain exactly why these changes occurred for each well.

Variations in results - cases where the level seems to peak and then decrease again - could be explained by a simple case of sample collection error or lab error. In some cases the arsenic could be attached to the plumbing and happens to be released at the time when the sample is collected, which would not be entirely representative of the overall water quality. This idea is corroborated by evidence found in the plumbing at one home in the own of Algoma (WUWN IG602) where the well had been replaced due to extremely high arsenic levels and then after replacing the well it continued to have arsenic levels above the standard. The sludge from a section of pipe at this property was analyzed by the WI State Lab of Hygiene, and was found to have high arsenic (6% of volume by weight). This has been seen in other wells as well.

Table V: Change in average arsenic levels over time (analyses of sampling data from 1998 and 2002-04 studies)

ARSENIC CONCENTRATION (ppb)

WUWN	Avg 98	Std Dev 98	Avg 02	Std Dev 02	+/-
FP 834	5.6	0.8	1.0	1.2	-4.6
ID 574	51.3	11.1	21.1	16.6	-30.1
FP 851	1.4	0.6	1.2	2.4	-0.3
HO 248	2.8	0.9	2.2	0.4	-0.6
ID 532	35.3	7.4	37.6	4.6	2.4
HN 392	2.6	0.4	4.0	0.8	1.4
HL 209	61.7	8.1	26.7	2.4	-35.0
KL 509	0.5	0.6	0.4	0.5	-0.2
HK 462	32.0	2.9	28.4	2.2	-3.6
HL 480	4.1	2.2	0.7	1.0	-3.4
IG 250	0.5	0.6	0.0	0.0	-0.5
HY 713	10.0	0.9	13.3	1.3	3.3

Std Dev: Standard Deviation

4.4 Physical Testing Results

Three wells were selected for physical testing. These were all replacement wells that were constructed according to the current DNR guidance, which meant they all had a minimum of 80 feet of casing through the StP. These wells will be referred to as King Well, located in the town of Algoma; the

Burgess Well, located in the town of Grand Chute, Outagamie County; and the Hendzel Well, located in the town of Angelica in Shawano County.

While the original proposal stated that "geo-physical" testing would be conducted, it became apparent during the study that only basic video viewing and pressure testing could realistically be completed. Thus, all three of these failed wells underwent pressure testing and were viewed with a down-hole video camera to ascertain if the casing was compromised. On the last well (Hendzel) the lower borehole was filled with bentonite and a 'free drain test' was also conducted. See Appendix G for details.

In summary, the results were inconclusive for all three of the wells. Small holes or cracks in the casing could not be seen with the video camera because visibility was poor due to debris falling from the inside of the casing and floating in the water column. Neither the pressure testing nor the 'free drain' tests indicated signs of compromised casing.

It is difficult to analyze these failed wells with these simple physical tests. Failed wells typically consist of a micro-environment with potential for extremely low pHs and the associated formation of sulfuric acid. Wells have been recorded with pHs in the range of 2 with documented casing deterioration (UWN EF044 and FO118). These holes likely start out small. If there was a small hole in any of the wells testing, visually seeing this hole with a video camera is very difficult, particularly very small pinholes. Yet these small holes can allow arsenic-laden water into the well when the well pump kicks on and/or when the natural downward gradients facilitate flow from outside the casing through the hole into the well. (It doesn't take much to exceed the standard of 10 ppb.) Also, using the pressure testing or 'free drain' method, it is believed that these small holes would not release water back into the casing once water was removed due to surface tension, and therefore not show up in the free drain test. Water will release to water but not to air; tiny pinholes may develop bubbles which will not drain under air, but will transfer under a "water to water" environment (D. Johnson, pers. comm.). This dynamic of water physics may have contributed to the inconclusive results for all 3 wells.

A more definitive way to ascertain the competency of the grout would be to use cement bond log, which would be very costly and out of the realm of this study. To date, it has not been done on arsenic wells in Wisconsin (D. Johnson, pers. comm., May 2004).

Despite the difficulty in proving this theory and the fact that compromised casing was not witnessed in this study, it has been seen on at least two other wells in the area (UWNs HL480 and EF044, Outagamie County). Therefore, the *potential* for well failure due to compromised casing underscores the importance of proper and conscientious grouting. This must be continually emphasized to drillers.

4.5 Additional Data Analysis

During the course of this study, the WDNR's recommendations continued to evolve, driven in part by the change in the arsenic standard. Many wells that were once considered "successful" under the former standard of 50 ppb were now considered "failures" under the new standard of 10 ppb. Sampling data from 45 Well Compensation Program replacement wells shows that 87% of them had arsenic concentrations less than 50 ppb after construction. Once the standard was lowered to 10 ppb, that success rate dropped to 51%. It was clear that the guidance needed to be modified at this point.

As the recommendations evolved, parameters other than casing depth were evaluated in terms of their role in reducing arsenic levels. Wells were analyzed and results evaluated based on the various aspects of the recommended drilling methods. In addition to the three wells in this study, additional data from replacement wells in areas of known elevated arsenic concentrations were evaluated. This data was collected by WDNR and the State Lab of Hygiene in a separate study (Sonzogni et al., 2004). This study looked at 80 wells, focusing primarily on chlorination issues. All wells in the comparison have a minimum of 80 feet of casing below the top of the StP; i.e., were constructed according to the guidance of the time. All 8 wells finished in the Cambrian were below 10 ppb arsenic, providing evidence that deeper cased wells tend to be more successful at meeting the new standard. Due to variability in geology and numerous other variables, direct comparisons are difficult, but evidence does indicate improvements with each of the methodologies incorporated into the current DNR recommendations (Table VI).

Table VI is a compilation of recently constructed wells. It indicates that wash rotary is superior to air rotary, Bradenhead (bottom up) grouting is far superior to tremie (top down) grouting, and the best method of post-construction disinfection is a light application of liquid sodium hypochlorite. This reflects current drilling recommendations which now require drillers to use wash rotary drilling of the lower borehole instead of air rotary, bradenhead grouting of the casing, light levels of disinfection with sodium hypochlorite (Sonzogni, et al, 2004), and the use of a desander in drilling the upper borehole to facilitate more effective grouting.

Table VI: Comparison of wells / arsenic results based on most recent (2004) WDNR recommendations (excluding casing depth)

Method		Arsenic Level: % <10 ppb	Arsenic Level: % >10 ppb
Lifting cutings	**Air Rotary vs.**	**52**	**48**
	Wash Rotary	**83**	**17**
Grouting	**Tremie Grouting vs.**	**39**	**61**
	Bradenhead Grouting	**92**	**8**
Disinfection	**Sodium Hypochlorite * vs.**	**81**	**19**
	Calcium Hypochlorite	**72**	**28**
	Sodium and Calcium Hypochlorite	**67**	**33**
	Light (<100ppm) Sodium Hypochlorite	**93**	**7**

* Drillers use a variety of disinfection methods and volumes. Sodium hypochlorite (liquid bleach) typically represents ~ 250-500 ppm chlorine solution. Calcium hypochlorite (dry bleach) means 2-4 handfuls of pellets, ~ 500 ppm of chloride solution. The sodium and calcium represents drillers who use both types of hypochlorite, ~700 ppm chloride solution.

5. Conclusions

As stated previously, there were four objectives for conducting this study. Following is a statement of the objective and a summary of the conclusion for each objective.

Objective #1: Is current WDNR guidance having the intended results of reducing arsenic levels in private wells?

In evaluating the sampling results, there was generally not a greater success rate for wells that had 80 feet of casing into the StP than there were for wells that did not follow the guidance. It did appear that the level of arsenic in the two very deep cased wells that were drilled or reconstructed through the StP and draw water from the Cambrian Sandstone, and the two wells that were shallow cased and draw water from the Galena Platteville limestone, remained low throughout the study period. These findings are consistent with the WDNR's newest (2004) guidance (Appendix G) which recommends drilling wells to draw water from an aquifer other than the StP.

Objective # 2: Are there seasonal variations in arsenic levels?

There has been anecdotal evidence that suggests that arsenic levels may change with the seasons, specifically would be higher during the autumn months. There does not appear to be a consistent pattern of seasonal variation in arsenic levels in the wells sampled in this study. Further study is probably not warranted, since this is a health issue and thus slight seasonal fluctuations are really of little consequence in the overall picture of arsenic mitigation or avoidance.

Objective #3: Do arsenic levels in individual wells increase over time?

All three tables showing the results address this question, particularly Table III since it includes data going back to 1997. While results did fluctuate for each well, the wells sampled during this study did not show a pattern of significant increases over time. This was true for all wells, including those from the Weissbach *et al* 1998 study which were re-sampled as part of this study. However, WDNR staff (O'Connor, Heinen, Johnson, Paplham) have seen significant increases in other wells which were not part of this study. It is believed that a complex set of factors may trigger geo-chemical processes which result in dramatic increases in arsenic levels in individual wells.

Objective # 4: Are wells constructed according to guidance failing because of casing failure?

The limited physical testing conducted on the casings of 3 failed replacement wells was not conclusive in determining why these wells failed.

Statistical Analysis

In general, the variations in sampling results that occurred made a formal statistical analysis of the results difficult, and not particularly meaningful. It is known that arsenic levels can vary from day to day, even hour to hour, and from one well to another with similar geology, age, and well construction. This variability, driven in part by the complexity of the geology, well usage, and geochemical triggers, adds to the complexity of the arsenic problem. It is why homeowners in areas where arsenic is known to exist are urged to sample their water regularly.

6. Recommendations

1. Based on these findings and other current information (see the arsenic page on the WDNR website at http://www.dnr.wi.gov/org/water/dwg/arsenic/index.htm to stay informed of recent findings and policy) it is our recommendation that well drillers follow the most recent (2004) WDNR's guidance to drill wells that avoid drawing water from the StP, as shown in Appendix G. The most important result of this study and its conclusions is that it provides support for WDNR's recent and on-going

efforts to require virtually the entire Arsenic Advisory Area (actually all of Outagamie and Winnebago Counties) be under a Special Casing Requirement. The goal of this guidance is to completely case off both the StP and the PdC formations and draw water from the Cambrian, or to draw from the upper limestone (Galena-Platteville) formation where water is available. In addition, as on-going studies (e.g. Gotkowitz, 2004) continue to emphasize the complexity of the arsenic problem, it has been suggested that in areas with significant development density, shared or cluster wells, and even municipal wells may be the best option.

2. Well drillers should be educated and vigilant about proper well construction techniques in the Arsenic Advisory Area. Although observing well drillers for compliance is increasingly difficult due to WDNR budget cuts, this should be done whenever possible to create an equal playing field amongst drillers. Enforcement should be pursued where warranted so that drillers doing the job properly are not beat out on bids by drillers not following the guidance and/or Special Casing Requirements.

3. In addition, in order to minimize the public health risk, residents in the arsenic area should be encouraged to test their water often, at a minimum on an annual basis, to ensure it is – and stays - below the standard. It is best to sample at different times of the year, since seasonal variations appear to exist, but not in a consistent pattern.

4. Towns and other units of government should be encouraged to get involved in this public health issue through information and education programs (e.g., town newsletters, informational flyers for new homeowners, etc.), and by implementing programs such as the town-based sampling model, and making this program self-sustaining.

5. WDNR should take a proactive role and work with local units of government on planning and land use issues to minimize the exposure and subsequent health affects of arsenic. Development continues to increase quite rapidly in this area, and Smart Growth Comprehensive Planning is very important to minimize natural resource conflicts and impacts. (Again, due to budget cuts and Drinking and Groundwater staff reductions, this is, unfortunately, increasingly difficult to accomplish.)

6. It is also recommended that further research be conducted on the low-level arsenic release mechanism of reduction and/or replacement reactions, and also on the newest guidance to test its effectiveness.

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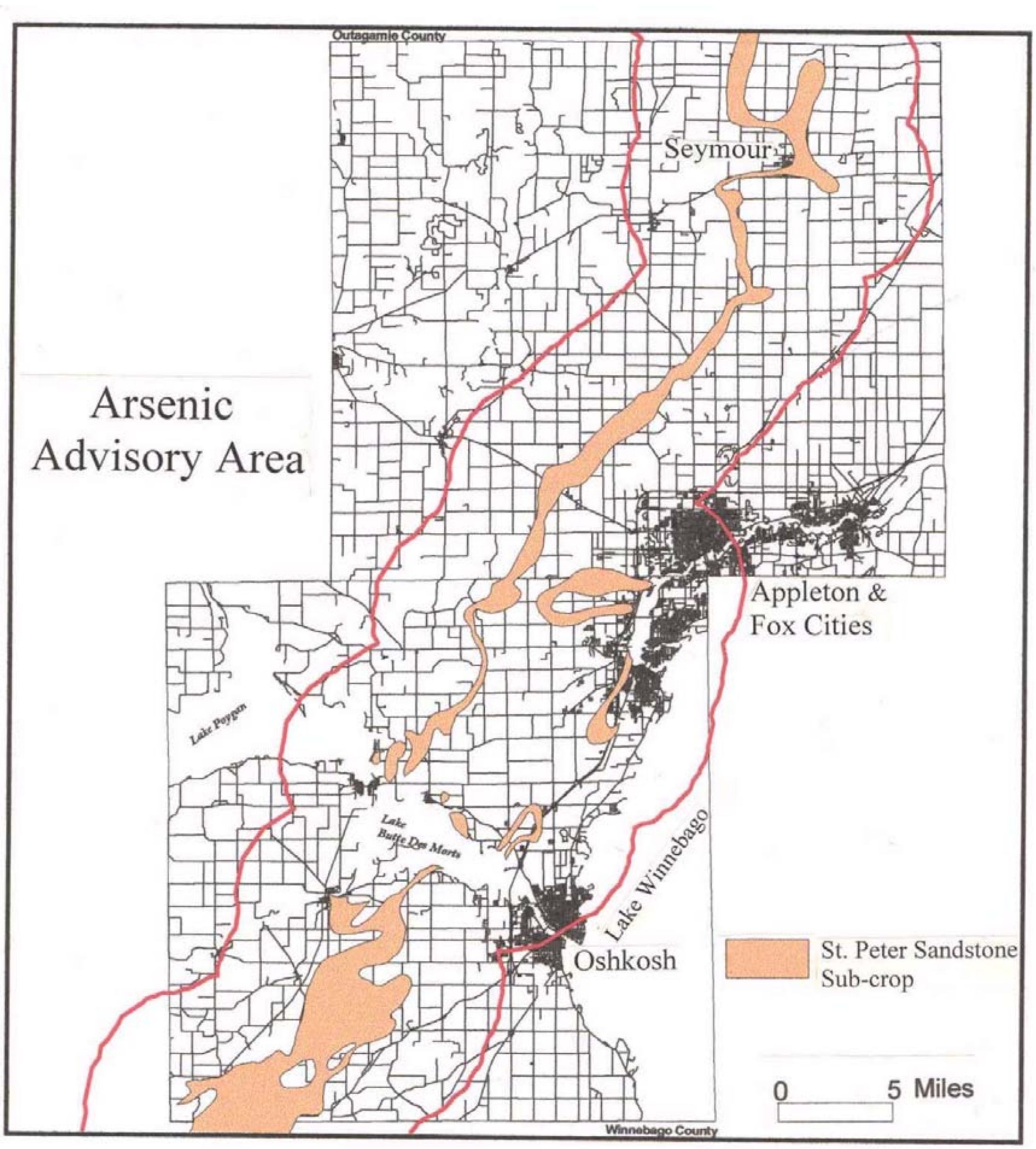
See Web Pages http://www.dnr.wi.gov/org/water/dwg/arsenic/index.htm **for Additional and Updated Information**

Appendix A

Map of Arsenic Advisory Area



Appendix B

Well Driller Guidance for Well Construction in Areas with Naturally Occurring Arsenic Water Quality Problems (1998)

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Well Driller Guidance for Well Construction in Areas with

Naturally Occurring Arsenic Water Quality Problems

Any drillers constructing water supply wells in the designated areas of **Outagamie** and **Winnebago Counties**, as shown on the attached map should seriously review this advisory information. Please note references to **Brown County.**

Findings

1. Numerous well water samples indicate arsenic occurs naturally in water supply wells, in eastern Outagamie and Winnebago Counties, along a line stretching roughly from Seymour to Oshkosh. Approximately 32 percent of the wells sampled in this area have water with detectable levels of arsenic, while 3.5 percent of the wells have water with arsenic levels that exceed the drinking water standard of 50 parts per billion (ppb). With the exception of Brown County, studies conducted on wells beyond Outagamie and Winnebago Counties have found arsenic levels above 50 ppb in only one well, which is in Shawano County. This means the potential for elevated arsenic levels exists outside the advisory areas, but not enough information is available at this time to extend the advisory. The area west of the City of Oshkosh, primarily in the Town of Algoma, appears to have a higher incidence of elevated arsenic levels.

2. Limited sample results show elevated arsenic levels in specific areas within the Townships of Hobart and Lawrence in western Brown County.

3. Sample results show arsenic occurs more commonly in wells that are open to the upper St. Peter sandstone, but may not be limited to this sandstone only. Well water with low pH or extremely high iron may be an indicator of high arsenic levels, although this is not always the case. Not every well open to the St. Peter sandstone will have arsenic in the water.

Guidance

1. **Based on existing information, wells should be constructed to withdraw water from the upper (Platteville/Galena) and lower (Prairie du Chien) limestones in preference to the St. Peter sandstone.**

2. **The top 80 feet of the St. Peter sandstone should be cased off if it is necessary to penetrate that formation.** Out experience tells us this will eliminate or reduce the bulk of the arsenic problems. There are no guarantees, regardless of well construction.
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3. **Well drillers should contact Gary Paplham at the Lower Fox River Basin Office in Green Bay (920-448-5132) prior to construction of wells in the Townships of Hobart and Lawrence in western Brown County.** Mr. Paplham can provide you with information on the exact areas with known arsenic problems, and is also responsible for Outagamie County. Kelley O'Connor at our Oshkosh Service Center (920-424-3050) is responsible for Winnebago County.

4. **A water sample should be collected and submitted to a certified laboratory for total arsenic analysis, upon completion of the well.** This recommendation applies to wells drilled between the 5 mile boundary lines shown on the map, in addition to new wells drilled into the St. Peter sandstone in Brown County, west of the Fox River. The laboratory results should be sent directly to the owner, who can contact DNR if the arsenic concentration exceeds the drinking water standard of 50 ppb. An additional arsenic sample should be collected by the owner after the well has been in operation for a year and any time a change in water quality is noticed.

5. Advise any well owners/clients with arsenic water quality problems that water treatment is an alternate option to new well construction or reconstruction. Only state Department of Commerce approved devices are allowable. A list of these can be obtained through the Bureau of Drinking Water & Groundwater in Madison at 608-266-3415 or the Northeast Region Drinking Water Offices at 920-492-5885. Currently only distillation units are acceptable, as the approval for reverse osmosis units has been rescinded.

6. **Well drillers and pump installers, when talking with well owners and users in the designated areas, should inform them of this advisory.** You should suggest that a water sample be taken for arsenic from existing wells that are of unknown construction or are known to be finished in the upper sandstone. Customers should be informed of options available to solve or prevent arsenic contaminated drinking water. You should tell well owners or users that the buffered 5 mile advisory area is an approximation on the map and may actually be greater in certain areas and less than 5 miles in other areas. This is important information that the customer can utilize in decisions about their water supply system and that you can provide as their water quality professional.

Appendix C

Special Well Casing Pipe Depth Area (2002)

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DATE: April 8, 2002 FILE REF: 3320

TO: Wisconsin Licensed Well Drillers

FROM: Mark Putra – Chief, Private Water Systems Section

SUBJECT: **Special Well Casing Depth Area – Towns of Algoma & Omro, Winnebago Co**.

A "Special Well Casing Pipe Depth Area" is herewith established for the area described below. Within this area new wells must be constructed to more stringent standards as indicated below.

This area includes portions of the western part of the Town of Algoma and a north-south strip of land in the northeastern portion of the Town of Omro, Winnebago County. The establishment of this "Special Casing Depth Area" is based on the number and percentage of wells within this area that produce water with high concentrations of arsenic. This "Special Casing Depth Area" is established under the Department's authority provided by Section NR 812.12(3), Wisc. Admin. Code (State Private Well Construction & Pump Installation Code). This limited construction requirement area is located within the much larger "Arsenic Advisory Area" established by the Department in 1993.

LOCATION

This "Special Well Casing Pipe Depth Area" includes approximately16 square miles situated just west of the City of Oshkosh in Winnebago County. This roughly square area is bounded on the north by Lake Butte Des Morts, on the east by Highway 41, on the south by County Highway K, and on the west by County Highway FF. This area is extends west to County Highway FF in order to include the "Galena-Black River Escarpment" where the sulfide-cement horizon could be present in the subsurface. Identifiable landmarks and roads delineate this area so the boundaries will be easily recognizable to Licensed Well Drillers and Department program personnel. (See Figure 1)

This area is described in detail as follows: Those portions of Sections 7, 8, 9 & 16 lying south of Lake Butte Des Morts, and all of Sections 17, 18, 19, 20, 21, 28, 29 & 30, T18N, R16E, Town of Algoma; The portion of the E ½ of Section 11, that portion of the SE ¼ of Section 2 and those portions of Sections 1 & 12 lying south of Lake Butte Des Morts, the E ½ of Sections 14, 23 & 26, and all of Sections 13, 24 & 25, T18N, R15E, Town of Omro (east part), all in Winnebago County.

CONTAMINANT
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Naturally occurring inorganic arsenic.

WELL CASING PIPE DEPTH SETTING REQUIREMENTS

Within this "Special Casing Pipe Depth Area" new and reconstructed private bedrock wells shall be installed according to one of following two options:

Option A: This option is allowed only with written Department approval on a well by well basis, and then only within that portion of Section 9 lying south of Lake Butte Des Morts and that portion of Section 16 lying north of Highway 21, T18N, R16E, Town of Algoma (These sections lie east of Oakwood Road and west of Highway 41). When approval is granted, a well may be constructed using the minimum Private Well Code (NR 812) specifications, but then only if the well uses just the upper Galena-Platteville Dolomite aquifer. The Galena-Platteville formation is the first bedrock formation encountered in the eastern portion of this Special Casing Depth Area. If an approval is granted under Option A, then the lower open bedrock drillhole of the well may not extend deeper than 10 feet above the base of the Galena-Platteville Dolomite. If the open bedrock drillhole is accidentally extended deeper for any other reason, then it shall be back-filled with neat cement grout up to a level at least 10 feet above the base of the Galena-Platteville formation. In order to accomplish this back filling, a tremie pipe shall be extended to the bottom of the hole and the grout shall be pumped in using an approved pressure method according to the requirements of s. NR 812.26.

Option B: Any bedrock well **not** constructed under Option A shall be constructed with cement grouted casing extending to the top of the Cambrian Sandstone. The Cambrian Sandstone lies below either the St. Peter Sandstone or the Prairie du Chien Dolomite. In most cases this option will necessitate grouted casing to extend to a depth anywhere from about 200 to 260 feet below the ground surface.***** Existing wells may also be reconstructed under this option by installing a liner, at least two inches smaller in diameter than the primary casing, to extend to the top of the Cambrian Sandstone. The liner shall have welded joints, be installed according to the requirements of s. NR 812.21(1) and shall be sealed in place with neat cement grout using an approved pressure method according to s. NR 812.20.
***** (Note: Consultation by the Well Driller with the Department's Northeast Region Program Staff is strongly recommended to help determine if the proposed casing depth setting will extend to the top of the Cambrian Sandstone.)

SPECIAL WELL CONSTRUCTION & DISINFECTION SPECIFICATIONS & METHODS

Within this 'Special Well Casing Depth Area', private wells constructed under Option B shall be constructed with alternate construction methods and more stringent standards for construction, grouting and disinfection. Wells shall be constructed, grouted and disinfected according to the following specifications:

1. For 6-inch diameter wells, the upper-enlarged drillhole shall have a diameter of 10 inches rather than the minimum 8 inches. For larger diameter wells, the upper-enlarged drillhole shall be at least four inches larger than the nominal diameter of the permanent well casing pipe.

2. The upper-enlarged drillhole shall be constructed using rotary mud-circulation methods. Rotary-air methods may **not** be used for this purpose. The size of the mud pit shall have a volume large enough to provide for efficient removal of drill cuttings. Further, a centrifuge sand separator shall be installed with the mud circulation system to help remove sand-sized cuttings.

3. If the water used to mix the drilling mud slurry has a pH below 6.5, it shall be carefully and slowly treated with soda ash to achieve a pH between 8 & 9.

4. The cement grout shall be ordered from a commercial concrete company and shall have a density of at least 15.2 lbs./ gallon, but preferably should have a density of 15.6 lbs./gal. The density shall be measured with a 'mud balance'.

5. The grout slurry shall be adequately screened in order to remove any aggregate before it enters the grout pump hopper.

6. The cement grout shall be pumped into the annular space using either the 'Bradenhead or the 'Grout Shoe' grouting method according to the requirements of s. NR 812.20.

7. At completion of the grouting procedure the grout shall flow out the top of the annular space with the same density as the grout being pumped from the hopper and shall have a density of at least 15.2 lbs./gal.

8. The grout shall be allowed to set for at least 72 hours before the construction of the lower bedrock drillhole is commenced.

9. The lower open bedrock drillhole shall be drilled using rotary-mud or "rotary-wash" drilling methods, i.e. rotary water-circulation methods. Rotary-air methods shall **not** be used for this purpose.

10. Upon completion of the well, an approved additive-free liquid chlorine (sodium hypochlorite) product shall be used to disinfect the well. Dry calcium hypochlorite products (granular or pellet type) shall **not** be used. The chlorine solution shall **not** have a concentration greater than 100 milligrams per liter (mg/l), and there shall be no more than 30 minutes of contact time in the well. After this time has elapsed, the solution shall be thoroughly flushed out of the well with water, **not** with air.

(Note: The Department may change these specifications for minimum casing depth, well construction and disinfection if conditions warrant. Notice for such changes will be provided.)

JUSTIFICATION FOR ESTABLISHING THIS "SPECIAL CASING DEPTH AREA"

Justification for establishing this "Special Casing Depth Area" is as follows:

1. This limited area within the Towns of Algoma and Omro has the highest density of arsenic-contaminated wells than any other similar area within the larger "Arsenic Advisory Area". Furthermore, some wells located in the Town of Algoma have produced water with some of the highest concentrations of arsenic found in the world.

2. Two new large housing subdivisions are planned within this area. These subdivisions will be located adjacent to the area that has a high density of arsenic-contaminated wells. Within the next 20 years, seventeen hundred living units are planned for these subdivisions to be located just west and south of the present subdivisions. Many new private wells are likely to be constructed for these proposed living units. If special casing depth requirements had not been established for this area, most new wells will be constructed according to the minimum Private Well Construction Code (NR 812) requirements and be open to the mineral-laden bedrock horizon within the bedrock. Scientists believe oxidation of these minerals causes arsenic to be released into the well water and surrounding groundwater.

3. Since 1993 about 90 wells have been constructed according to Department-recommended special construction specifications within the "Arsenic Advisory Area. More than eighty five percent of these wells have been successful according to the previous arsenic standard of 50 ug/l. Within the last year and a half these special construction & disinfection methods have been modified to be more stringent. These newly modified construction specifications and methods should significantly increase the chances that new wells constructed to these standards will be successful at meeting the newly established arsenic Safe Drinking Water Act standard of 10 ug/l. Further, even when wells, constructed to these more stringent standards are not successful at a criterion of 10 ug/l, these wells will produce water with much lower concentrations of arsenic compared to wells constructed according to minimum Private Well Code (NR 812) requirements. Lower arsenic concentrations will allow Department of Commerce approved treatment equipment systems to be more effective and efficient at removing arsenic from the water. Treatment systems will therefore be more feasible for reducing arsenic concentrations below the new drinking water standard.

4. Based on the results of research done over the past fifteen years, program staff and scientists from the Wisconsin Geological & Natural History Survey (WGNHS) believe that construction of new wells to these more stringent standards will reduce the risk of contamination to the regional groundwater system and reduce damage to the bedrock aquifers. Researchers from WGNHS who have extensively studied the arsenic problems of this area, also recommend that new wells be cased and grouted down to the top of the Cambrian Sandstone to reduce the exposure of groundwater to the Sulfide Cement Horizon and other deeper sulfide mineralization.

5. Water sample results from wells cased to and withdrawing water from the Cambrian Sandstone indicate the quality of the groundwater in this aquifer is low in arsenic, radium and other heavy metal contaminants.

6. Over a lifetime, the risk of developing cancer from consuming water containing arsenic at concentrations exceeding 50 parts per billion are very high compared to potential risks from other water contaminants. At the present time, scientific estimates of the risks of developing cancer from drinking the water from these wells over a lifetime could range anywhere from one in 1,000 to one in 100. These risks are very high compared to risks associated with groundwater contaminants like volatile organic chemicals (VOCs) or pesticides. A significant percent of the existing wells recently sampled in this area (127 of 1,273 wells – 10.0 %) exceed the previous 50 ug/l arsenic standard. More importantly, 513 wells (40.3 %) exceed the new standard of 10 ug/l.

7. The proposed "Special Casing Depth Area" is located within the "Arsenic Advisory Area". Within this larger area the Department already recommends that new wells be constructed to the more stringent well construction and disinfection specifications. Thus, these more stringent standards will not be a new concept for the residents of this area or for the Licensed Well Drillers who have been constructing wells to these standards within this area.

Appendix D

Letter Sent to Study Participants

~~~~~~

Date WUWN:

Current Resident
Street Address
City, WI Zip

Dear Resident:

SUBJECT: **SAMPLING OF PRIVATE WELLS AS PART OF AN ARSENIC RESEARCH PROJECT**

Safe drinking water is very important to all of us; therefore, the Wisconsin Department of Natural Resources (DNR) is conducting a research project to study the well water in Northeast Wisconsin. As you may know, several homeowners in your area have experienced problems with naturally occurring arsenic. You may be one of these homeowners. The primary purpose of this study is to help us understand what type of well construction is most effective in reducing or eliminating the presence of arsenic in well water. Since the wells in your township have the potential to produce water high in arsenic, I am inviting you to participate in this study.

If you choose to participate, we will do the following:

- Collect water samples five times: November, 2000, April, August, and December, 2001 and March, 2002. (The sampling can usually be done from an outside faucet.)
- Have the samples analyzed for arsenic.
  (**The samples are free - there are no costs for you to participate in this study**.)
- Send you the results.

If you are interested in participating in this project, please fill out the attached form and mail it back in the enclosed envelope by November 3, 2000. I will call you to discuss the sampling and to answer any questions you may have.

For more information, please call me at (920) 492-5593.

Sincerely,

Marcy McGrath
Drinking & Groundwater Specialist
~~~~~~

Please fill out and mail back to the DNR in the enclosed envelope.

Γ **Yes, I'm interested.** WUWN:
Please call me for more information.

Name: ______________________________

Address: ______________________________

____

Home Phone #: _______________________

Can you be reached at work? __________ **Work Phone #:** _______________________

Best time to call: _______________________

Best time to collect a water sample: ______________________________

Is water from outside faucets treated in any way (softener, etc.)? ______________________________

Have you had your water tested for arsenic? __________

Appendix E

Maps of Sampling Locations in Town of Algoma

Location of Wells Sampled for Arsenic in Algoma, WI

The data shown on this map have been obtained from various sources, and are of varying age, reliability and resolution. This map is not intended to be used for navigation, nor is this map an authoritative source of information about legal land ownership or public access. Users of this map should confirm the ownership of land through other means in order to avoid trespassing. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map.

WISCONSIN
DEPT. OF NATURAL RESOURCES

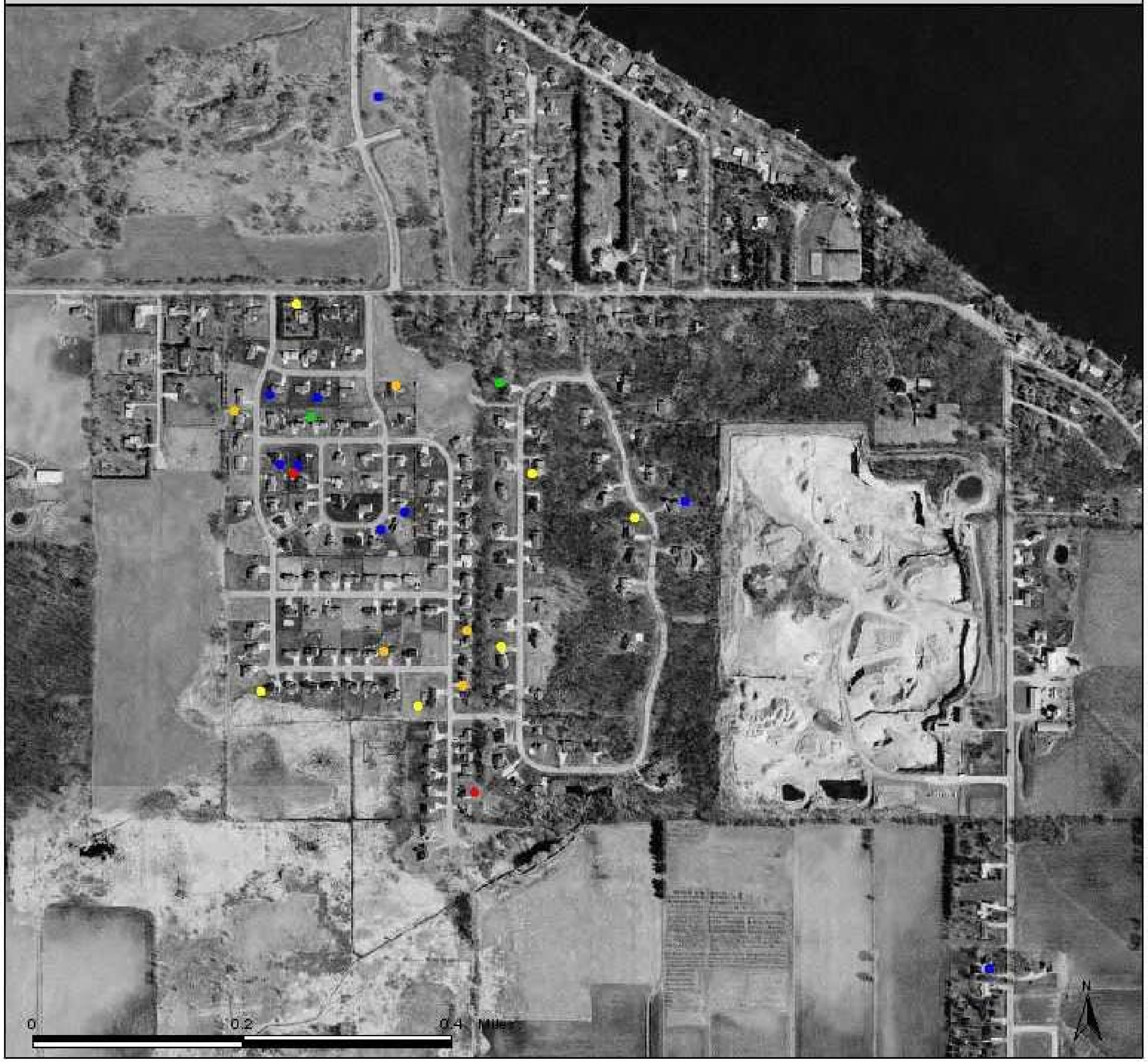
Legend

● Arsenic Testing Sites

Map Source: WDNR, 1992 Aerial Photo

Map Creator: L. Evenson March 2003

Arsenic Results in Northwest Portion of Town of Algoma



The data shown on this map have been obtained from various sources, and are of varying age, reliability and resolution. This map is not intended to be used for navigation, nor is this map an authoritative source of information about legal land ownership or public access. Users of this map should confirm the ownership of land through other means in order to avoid trespassing. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map.

WISCONSIN
DEPT. OF NATURAL RESOURCES

Legend

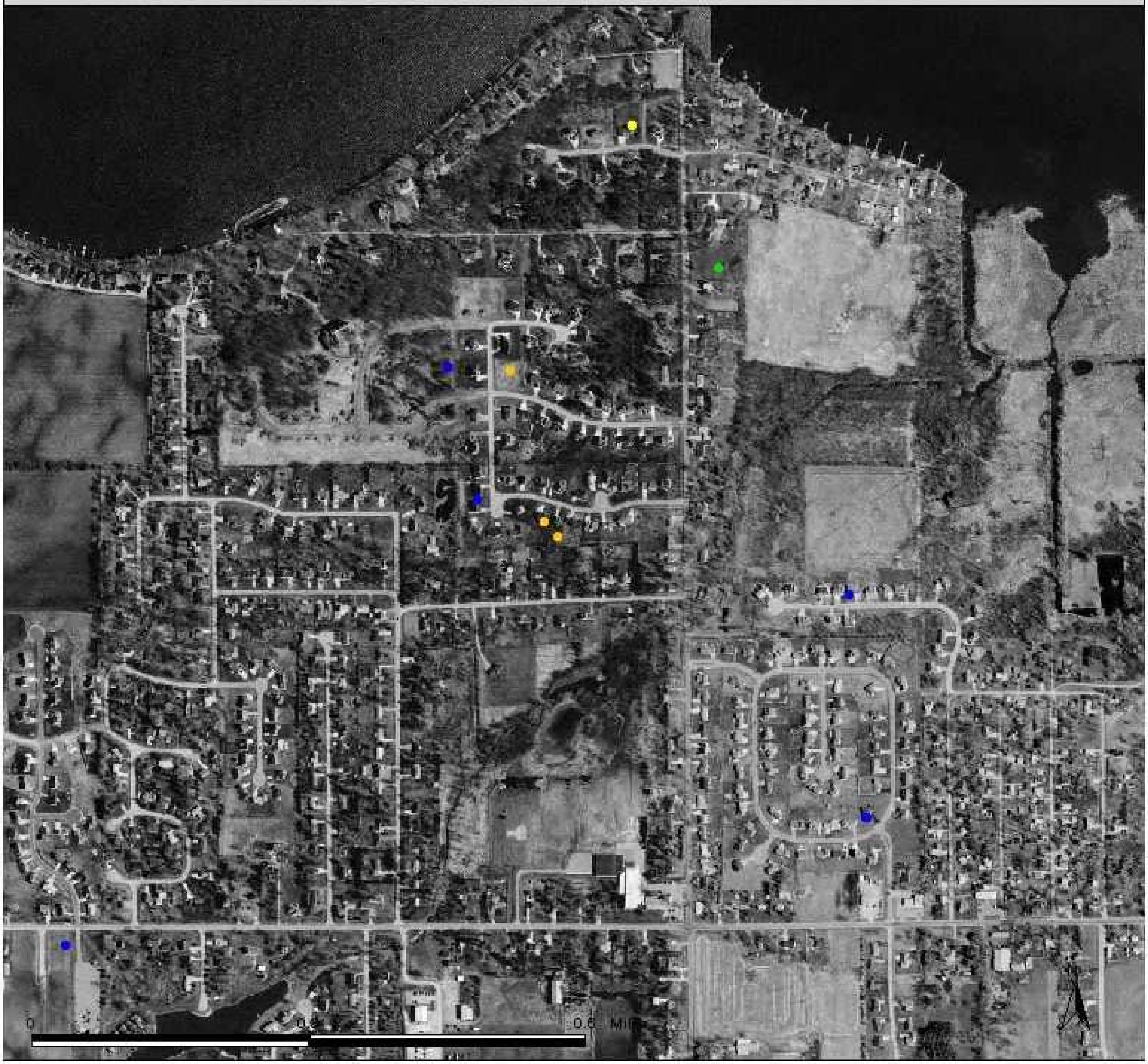
Arsenic Levels (ppb)

- 0 - 5
- 6 - 10
- 11 - 20
- 21 - 49
- 50 - 490

Map Source: WDNR, 1992 Aerial Photo

Map Creator: L. Evenson March 2003

Arsenic Results in Central Portion of Town of Algoma: North of STH 21



The data shown on this map have been obtained from various sources, and are of varying age, reliability and resolution. This map is not intended to be used for navigation, nor is this map an authoritative source of information about legal land ownership or public access. Users of this map should confirm the ownership of land through other means in order to avoid trespassing. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map.

WISCONSIN DEPT. OF NATURAL RESOURCES

Legend

Arsenic Levels (ppb)

- 0 - 5
- 6 - 10
- 11 - 20
- 21 - 49
- 50 - 490

Map Source: WDNR, 1992 Aerial Photo

Map Creator: L. Evenson March 2003

Arsenic Results in Central Portion of Town of Algoma: South of STH 21

The data shown on this map have been obtained from various sources, and are of varying age, reliability and resolution. This map is not intended to be used for navigation, nor is this map an authoritative source of information about legal land ownership or public access. Users of this map should confirm the ownership of land through other means in order to avoid trespassing. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map.

WISCONSIN
DEPT. OF NATURAL RESOURCES

Legend

Arsenic Levels (ppb)

- 0 - 5
- 6 - 10
- 11 - 20
- 21 - 49
- 50 - 490

Map Source: WDNR, 1992 Aerial Photo

Map Creator: L. Evenson March 2003

Appendix F

Sampling Results

Results for All Wells

STREET NAME	TOWNSHIP	WUWN	WELL CASING (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb)							IRON (ppm)	pH (S.U.)	CON. (umhos/cm)
						Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	AVERAGE	AVG DEV	Nov. 2000	Apr. 2001	Apr. 2001
Kirkwood Drive	Algoma	PR 751	0	1968/july	original	NT	490	415	445	439	447.3	21.4	NT	6.6	857
Emily Anne Drive	Algoma	CW 432	0	1989/nov	original	49	8.4	38.9	26.9	9.4	26.5	14.1	10	7.8	1101
Prairie Wood Drive	Algoma	CW 491	0	1989/oct	original	35	37	37	42.9	35.7	37.5	2.2	1.2	6.5	636
Prairie Wood Drive	Algoma	CY 269	0	1990/dec	original	0.6	0	0	0	0	0.1	0.2	0	7.7	971
Wylde Oak Road	Algoma	CW 948	0	1990/feb	original	NT	52	70.4	51.8	50.2	56.1	7.2	NT	7.8	671
Daniel Ct	Algoma	DD 170	0	1990/jan	original	50	85	79.6	83.3	60.5	71.7	13.1	0.74	7.3	736
Scarlett Oak Trail	Algoma	DF 607	0	1990/may	original	15	17	14.9	13.4	13.4	14.7	1.1	6.3	6.4	637
Oakwood Circle	Algoma	DF 608	0	1990/may	original	1	0	0	0	0	0.2	0.3	0.65	6.4	581
Shorehaven Court	Algoma	CY 294	0	1991/feb	original	9.2	8.8	12.2	10	8.5	9.7	1.1	0.98	6.4	653
Prairie Wood Drive	Algoma	DA 818	0	1991/march	original	17	28	24.9	23.1	21.6	22.9	2.9	0.76	7.8	676
Green Briar Trail	Algoma	HO 241	25	1994/feb	original	6.3	5.2	6.5	5.8	4.9	5.7	0.6	0.65	7.4	565
Emily Anne Drive	Algoma	HO 248	74	1994/jan	original	2.5	NT	NT	NT	1.9	2.2	0.3	2.3	NT	NT
Mielke Road	Osborn	HK 462	23	1994/may	original	29	27	29.4	31.1	25.3	28.4	1.8	26	6.8	908
CTY RD GG	Vinland	HY 713	26	1994/oct	original	12	12	13.4	14.9	14.3	13.3	1.1	1.7	6.5	667
Scarlet Oak Trail	Algoma	HW 842	25	1994/sept	original	18	20	19.1	20	17.5	18.9	0.9	1.2	6.6	604
Meadow View Lane	Algoma	ID 824	25	1995/feb	original	29	31	33.1	33.1	28.2	30.9	1.8	1.5	7.7	627
Weelaunee Drive	Utica	IG 250	23	1995/july	original	0	NT	NT	NT	0	0.0	0.0	0.74	NT	NT
Kortney Lane	Osborn	KL 509	39	1995/nov	original	0.7	NT	NT	NT	0	0.4	0.4	1.9	NT	NT
Sheboygan Street	Algoma	LT 966	83	1997/april	original	1	0	0	0	0	0.2	0.3	0.02	7	1154
Forest View	Algoma	LT 974	83	1997/april	original	42	47	44.4	42.2	45.2	44.2	1.6	4.6	6.5	677
Woodridge Drive	Algoma	LW 780	81	1997/aug	original	39	34	41.7	44.1	37.9	39.3	2.8	4.1	7.8	678
Countryside Court	Algoma	MC 344	85	1997/sept	original	37	38	43	41.7	28.4	37.6	3.9	4.9	6.9	680
Bellhaven Lane	Algoma	MY 031	limestone	1999/jan	original	2.9	2.2	3.3	1.9	1.7	2.4	0.6	2.2	8.1	835
Scarlet Oak Trail	Algoma	NF 423	0	1999/oct	original	3.4	2.1	3.2	4.1	7.4	4.0	1.4	0.09	6.6	1015
Kiely Way	Clayton	NN 769	14	1999/oct	original	11	11	10.9	12.1	12.8	11.6	0.7	0.67	7.9	414
Horseshoe Road	Algoma	NN 755	0	1999/sept	original	5.9	3.9	4.5	5.9	4.7	5.0	0.7	1.3	7.7	875
Pine Ridge Road	Algoma	NC 794	0	2000/april	original	0.9	0	0	0	0	0.2	0.3	0.47	6.2	1034
Leonard Point Road	Algoma	NR 875	87	2000/feb	original	14	12	13.5	13.4	15.3	13.6	0.8	0.39	7.8	559
Pine Ridge Road	Algoma	NR 856	85	2000/jan	original	21	23	24.5	22.9	22.1	22.7	0.9	2.5	6	650
Leonard Point Road	Algoma	OE 806	105	2000/july	original	0	1	1.2	0	0	0.4	0.5	0.15	7.8	801
Colleen Court	Algoma	OE 824	76	2000/july	original	1.9	1.6	1.4	2	0	1.4	0.6	3.9	8.2	672
Omro Road	Algoma	OD 664	limestone	2000/june	original	2.7	2.7	4.5	2.8	4.3	3.4	0.8	0.63	7.4	744
Honey Creek Road	Algoma	MS 144	125	2000/may	original	11	8.7	8.5	10.4	10.4	9.8	1.0	2.6	7.9	642
Apollo Court	Clayton	MS 148	24	2000/may	original	0.8	1.1	1.4	0	0	0.7	0.5	0	7.1	895
Leila Mae Lane	Algoma	OD 623	0	2000/may	original	4.2	5.3	5.7	5.3	4.9	5.1	0.4	0.86	7.4	1079
French Road (A)*	Osborn	FO 118	114	1993/march	reconstructed	10	NA	NA	NA	NA	10.0	0.0	3.5	NA	NA
Witzel Avenue	Algoma	ID 532	80	1994/dec	reconstructed	35	42	38.5	41.5	31	37.6	3.7	4.4	7.4	685
Westbreeze Drive	Algoma	ID 536	100	1994/dec	reconstructed	24	17	21.5	19.4	18.3	20.0	2.2	1.8	6.9	637
Amy Jo Drive	Algoma	FP 834	210	1994/feb	reconstructed	0.8	1.2	2.9	0	0	1.0	0.9	4.5	8.1	610
Emily Anne Drive	Algoma	FP 851	213	1994/march	reconstructed	0	4.7	0	0	NA	1.2	1.8	5.7	8.2	602
Danbe Road	Algoma	ID 574	92	1995/feb	reconstructed	45	31	5.8	15.9	7.9	21.1	13.5	5	7.7	837
Amy Jo Drive	Algoma	KS 445	86	1996/feb	reconstructed	25	17	20.9	13.4	9.4	17.1	4.6	15	7.3	652
Meadowview Lane	Algoma	KS 461	96	1996/march	reconstructed	17	15	16.4	16.5	15.4	16.1	0.7	1.3	7.5	550
Emily Anne Drive	Algoma	LK 372	81	1997/march	reconstructed	84	67	62.5	52.3	42.3	61.6	11.5	6.9	6.5	661
Mayflower Drive	Grand Chute	HL 209	183	1994/feb	replacement	30	27	27.6	25	23.8	26.7	1.8	11	7.7	783
Quarry Road	Center	HN 392	130	1994/june	replacement	4.6	NT	NT	NT	3.4	4.0	0.6	17	NT	NT
STH 168	Seymour	HL 480	82	1994/sept	replacement	1.4	NT	NT	NT	0	0.7	0.7	1.6	NT	NT
9th Street	Algoma	HW 851	81	1994/sept	replacement	35	39	36.4	38.5	35.4	36.9	1.5	1.8	6.3	612
Westbreeze Drive	Algoma	LL 499	111	1996/dec	replacement	32	28	33.9	31.9	34.4	32.0	1.7	5	7.6	657
Oakwood Avenue	Clayton	KQ 450	94	1996/june	replacement	150	150	127	156	157	148.0	8.4	3.4	7.8	717
Forte Road	Algoma	MC 381	82	1997/nov	replacement	2.1	1.9	2.1	1.8	2.2	2.0	0.1	2	7.7	530

Results for All Wells

STREET NAME	TOWNSHIP	WUWN	WELL CASING (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb)							IRON (ppm)	pH (S.U.)	CON. (umhos/cm)
						Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	AVERAGE	AVG DEV	Nov. 2000	Apr. 2001	Apr. 2001
Grandview Road	Winchester	MR 920	64	1998/aug	replacement	0.7	0.9	0	0	0	0.3	0.4	1.7	7.8	648
Emily Anne Drive	Algoma	MG 231	87	1998/sept	replacement	2	1.7	1.1	0	0	1.0	0.8	3.8	7.4	536
Westbreeze Drive	Algoma	MG 232	87	1998/sept	replacement	5.6	**14**	**14.4**	**13.3**	**13.5**	**12.2**	2.6	3	7.2	656
Elm Road (A)*	Angelica	MY 397	93	1999/feb	replacement	**570**	**1100**	NA	NA	NA	**835.0**	265.0	240	3.5	NT
Center Road	Clayton	NK 899	87	1999/nov	replacement	**14**	**19**	**15**	**22.3**	**11.7**	**16.4**	3.4	7.2	7.7	647
Green Briar Trail	Algoma	NN 786	123	1999/oct	replacement	**12**	**11**	**12.1**	**11**	**10**	**11.2**	0.7	4.2	7.4	627
Westmoor Road	Algoma	NN 725	95	1999/sept	replacement	0	0.8	1.1	0	1.1	0.6	0.5	4.4	7.8	661
Marquis Road	Algoma	NX 703	88	2000/jan	replacement	5.6	3.8	4.8	3.9	3.3	4.3	0.7	2.4	7.9	907
Forte Road	Algoma	OL 569	162	2000/oct	replacement	3.9	4	2.5	1.7	2.2	2.9	0.9	4.4	6.1	701
Westbreeze Drive	Algoma	OL 542	124	2000/sept	replacement	**71**	**20**	**29.1**	**26.2**	**23.8**	**34.0**	14.8	8.6	7.6	695
Elm Road (B)*	Angelica	OP 469	115	2001/april	replacement	NA	NA	1.6	1.3	3.2	2.0	0.8	NT	NT	NT
French Road (B)*	Osborn	OQ 983	195	2001/april	replacement	NA	5.2	2.9	1.7	2	3.0	1.1	NA	6.8	649
Green Briar Trail	Algoma	OP 734	149	2001/jan	replacement	NT	**19**	**12.7**	**18.1**	**19.6**	**17.4**	2.3	NT	7.9	656

Arsenic Results Key

<10 ppb

10 - 49 ppb

> 50 ppb

NA = Not Available

NT = Not Tested

AVG DEV = Average Deviation

ppb = parts per billion

ppm = parts per million

CON = Conductivity

Results for Wells With Minimum Casing

STREET NAME	TOWNSHIP	WUWN	WELL CASING (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb)						IRON (ppm)	pH (S.U.)	CON (umhos/cm)
						Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	Average	Nov. 2000	Apr. 2001	Apr. 2001
Kirkwood Drive	Algoma	PR 751	0	1968/july	original	NT	490	415	445	439	447.3	NT	6.6	857
Emily Anne Drive	Algoma	CW 432	0	1989/nov	original	49	8.4	38.9	26.9	9.4	26.5	10	7.8	1101
Prairie Wood Drive	Algoma	CW 491	0	1989/oct	original	35	37	37	42.9	35.7	37.5	1.2	6.5	636
Prairie Wood Drive	Algoma	CY 269	0	1990/dec	original	0.6	0	0	0	0	0.1	0	7.7	971
Wylde Oak Road	Algoma	CW 948	0	1990/feb	original	NT	52	70.4	51.8	50.2	56.1	NT	7.8	671
Daniel Ct	Algoma	DD 170	0	1990/jan	original	50	85	79.6	83.3	60.5	71.7	0.74	7.3	736
Oakwood Circle	Algoma	DF 608	0	1990/may	original	1	0	0	0	0	0.2	0.65	6.4	581
Scarlett Oak Trail	Algoma	DF 607	0	1990/may	original	15	17	14.9	13.4	13.4	14.7	6.3	6.4	637
Shorehaven Court	Algoma	CY 294	0	1991/feb	original	9.2	8.8	12.2	10	8.5	9.7	0.98	6.4	653
Prairie Wood Drive	Algoma	DA 818	0	1991/march	original	17	28	24.9	23.1	21.6	22.9	0.76	7.8	676
Scarlet Oak Trail	Algoma	NF 423	0	1999/oct	original	3.4	2.1	3.2	4.1	7.4	4.0	0.09	6.6	1015
Horseshoe Road	Algoma	NN 755	0	1999/sept	original	5.9	3.9	4.5	5.9	4.7	5.0	1.3	7.7	875
Pine Ridge Road	Algoma	NC 794	0	2000/april	original	0.9	0	0	0	0	0.2	0.47	6.2	1034
Leila Mae Lane	Algoma	OD 623	0	2000/may	original	4.2	5.3	5.7	5.3	4.9	5.1	0.86	7.4	1079
Kiely Way	Clayton	NN 769	14	1999/oct	original	11	11	10.9	12.1	12.8	11.6	0.67	7.9	414
Mielke Road	Osborn	HK 462	23	1994/may	original	29	27	29.4	31.1	25.3	28.4	26	6.8	908
Weelaunee Drive	Utica	IG 250	23	1995/july	original	0	NT	NT	NT	0	0.0	0.74	NT	NT
Apollo Court	Clayton	MS 148	24	2000/may	original	0.8	1.1	1.4	0	0	0.7	0	7.1	895
Green Briar Trail	Algoma	HO 241	25	1994/feb	original	6.3	5.2	6.5	5.8	4.9	5.7	0.65	7.4	565
Scarlet Oak Trail	Algoma	HW 842	25	1994/sept	original	18	20	19.1	20	17.5	18.9	1.2	6.6	604
Meadow View Lane	Algoma	ID 824	25	1995/feb	original	29	31	33.1	33.1	28.2	30.9	1.5	7.7	627
CTY RD GG	Vinland	HY 713	26	1994/oct	original	12	12	13.4	14.9	14.3	13.3	1.7	6.5	667
Kortney Lane	Osborn	KL 509	39	1995/nov	original	0.7	NT	NT	NT	0	0.4	1.9	NT	NT

Arsenic Results Key

<10 ppb

10 - 49 ppb

> 50 ppb

NA = Not Available

NT = Not Tested

ppb = parts per billion

ppm = parts per million

CON = Conductivity

Results for Wells Constructed According to Guidance

STREET NAME	TOWNSHIP	WUWN	WELL CASING (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb)						IRON (ppm)	pH (S.U.)	CON (umhos/cm)
						Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	AVERAGE	Nov. 2000	Apr. 2001	Apr. 2001
Grandview Road	Winchester	MR 920	64	1998/aug	replacement	0.7	0.9	0	0	0	0.3	1.7	7.8	648
Emily Anne Drive	Algoma	HO 248	74	1994/jan	original	2.5	NT	NT	NT	1.9	2.2	2.3	NT	NT
Colleen Court	Algoma	OE 824	76	2000/july	original	1.9	1.6	1.4	2	0	1.4	3.9	8.2	672
Witzel Avenue	Algoma	ID 532	80	1994/dec	reconstructed	35	42	38.5	41.5	31	37.6	4.4	7.4	685
9th Street	Algoma	HW 851	81	1994/sept	replacement	35	39	36.4	38.5	35.4	36.9	1.8	6.3	612
Emily Anne Drive	Algoma	LK 372	81	1997/march	reconstructed	84	67	62.5	52.3	42.3	61.6	6.9	6.5	661
Woodridge Drive	Algoma	LW 780	81	1997/aug	original	39	34	41.7	44.1	37.9	39.3	4.1	7.8	678
STH 168	Seymour	HL 480	82	1994/sept	replacement	1.4	NT	NT	NT	0	0.7	1.6	NT	NT
Forte Road	Algoma	MC 381	82	1997/nov	replacement	2.1	1.9	2.1	1.8	2.2	2.0	2	7.7	530
Sheboygan Street	Algoma	LT 966	83	1997/april	original	1	0	0	0	0	0.2	0.02	7	1154
Forest View	Algoma	LT 974	83	1997/april	original	42	47	44.4	42.2	45.2	44.2	4.6	6.5	677
Countryside Court	Algoma	MC 344	85	1997/sept	original	37	38	43	41.7	28.4	37.6	4.9	6.9	680
Pine Ridge Road	Algoma	NR 856	85	2000/jan	original	21	23	24.5	22.9	22.1	22.7	2.5	6	650
Amy Jo Drive	Algoma	KS 445	86	1996/feb	reconstructed	25	17	20.9	13.4	9.4	17.1	15	7.3	652
Emily Anne Drive	Algoma	MG 231	87	1998/sept	replacement	2	1.7	1.1	0	0	1.0	3.8	7.4	536
Westbreeze Drive	Algoma	MG 232	87	1998/sept	replacement	5.6	14	14.4	13.3	13.5	12.2	3	7.2	656
Center Road	Clayton	NK 899	87	1999/nov	replacement	14	19	15	22.3	11.7	16.4	7.2	7.7	647
Leonard Point Road	Algoma	NR 875	87	2000/feb	original	14	12	13.5	13.4	15.3	13.6	0.39	7.8	559
Marquis Road	Algoma	NX 703	88	2000/jan	replacement	5.6	3.8	4.8	3.9	3.3	4.3	2.4	7.9	907
Danbe Road	Algoma	ID 574	92	1995/feb	reconstructed	45	31	5.8	15.9	7.9	21.1	5	7.7	837
Elm Road	Angelica	MY 397	93	1999/feb	replacement	570	1100	NA	NA	NA	835.0	240	3.5	NA
Oakwood Avenue	Clayton	KQ 450	94	1996/june	replacement	150	150	127	156	157	148.0	3.4	7.8	717
Westmoor Road	Algoma	NN 725	95	1999/sept	replacement	0	0.8	1.1	0	1.1	0.6	4.4	7.8	661
Meadowview Lane	Algoma	KS 461	96	1996/march	reconstructed	17	15	16.4	16.5	15.4	16.1	1.3	7.5	550
Westbreeze Drive	Algoma	ID 536	100	1994/dec	reconstructed	24	17	21.5	19.4	18.3	20.0	1.8	6.9	637
Leonard Point Road	Algoma	OE 806	105	2000/july	original	0	1	1.2	0	0	0.4	0.15	7.8	801
Westbreeze Drive	Algoma	LL 499	111	1996/dec	replacement	32	28	33.9	31.9	34.4	32.0	5	7.6	657
French Road	Osborn	FO 118	114	1993/march	reconstructed	10	NA	NA	NA	NA	10.0	3.5	NA	NA
Elm Road	Angelica	OP 469	115	2001/april	replacement	NA	NA	1.6	1.3	3.2	2.0	NA	NA	NA
Green Briar Trail	Algoma	NN 786	123	1999/oct	replacement	12	11	12.1	11	10	11.2	4.2	7.4	627
Westbreeze Drive	Algoma	OL 542	124	2000/sept	replacement	71	20	29.1	26.2	23.8	34.0	8.6	7.6	695
Honey Creek Road	Algoma	MS 144	125	2000/may	original	11	8.7	8.5	10.4	10.4	9.8	2.6	7.9	642
Quarry Road	Center	HN 392	130	1994/june	replacement	4.6	NT	NT	NT	3.4	4.0	17	NT	NT
Green Briar Trail	Algoma	OP 734	149	2001/jan	replacement	NT	19	12.7	18.1	19.6	17.4	NT	7.9	656
Forte Road	Algoma	OL 569	162	2000/oct	replacement	3.9	4	2.5	1.7	2.2	2.9	4.4	6.1	701
Mayflower Drive	Grand Chute	HL 209	183	1994/feb	replacement	30	27	27.6	25	23.8	26.7	11	7.7	783
French Road	Osborn	OQ 983	195	2001/april	replacement	NA	5.2	2.9	1.7	2	3.0	NA	6.8	649
Amy Jo Drive	Algoma	FP 834	210	1994/feb	reconstructed	0.8	1.2	2.9	0	0	1.0	4.5	8.1	610
Emily Anne Drive	Algoma	FP 851	213	1994/march	reconstructed	0	4.7	0	0	NA	1.2	5.7	8.2	602
Bellhaven Lane	Algoma	MY 031	limestone	1999/jan	original	2.9	2.2	3.3	1.9	1.7	2.4	2.2	8.1	835
Omro Road	Algoma	OD 664	limestone	2000/june	original	2.7	2.7	4.5	2.8	4.3	3.4	0.63	7.4	744

Arsenic Results Key

<10 ppb

10 - 49 ppb

> 50 ppb

NA = Not Available

NT = Not Tested

ppb = parts per billion

ppm = parts per million

CON = Conductivity

Results For Wells in Town of Algoma

STREET NAME	WUWN	WELL CASING* (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb)						IRON (ppm)	pH (S.U.)	CON. (umhos/cm)
					Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	Avg. Conc.	Nov. 2000	Apr. 2001	Apr. 2001
Kirkwood Drive	PR 751	0	1968/july	original	NT	490	415	445	439	447.3	NT	6.6	857
Emily Anne Drive	CW 432	0	1989/nov	original	49	8.4	38.9	26.9	9.4	26.5	10	7.8	1101
Prairie Wood Drive	CW 491	0	1989/oct	original	35	37	37	42.9	35.7	37.5	1.2	6.5	636
Prairie Wood Drive	CY 269	0	1990/dec	original	0.6	0	0	0	0	0.1	0	7.7	971
Wylde Oak Road	CW 948	0	1990/feb	original	NT	52	70.4	51.8	50.2	56.1	NT	7.8	671
Daniel Ct	DD 170	0	1990/jan	original	50	85	79.6	83.3	60.5	71.7	0.74	7.3	736
Scarlett Oak Trail	DF 607	0	1990/may	original	15	17	14.9	13.4	13.4	14.7	6.3	6.4	637
Oakwood Circle	DF 608	0	1990/may	original	1	0	0	0	0	0.2	0.65	6.4	581
Shorehaven Court	CY 294	0	1991/feb	original	9.2	8.8	12.2	10	8.5	9.7	0.98	6.4	653
Prairie Wood Drive	DA 818	0	1991/march	original	17	28	24.9	23.1	21.6	22.9	0.76	7.8	676
Scarlet Oak Trail	NF 423	0	1999/oct	original	3.4	2.1	3.2	4.1	7.4	4.0	0.09	6.6	1015
Horseshoe Road	NN 755	0	1999/sept	original	5.9	3.9	4.5	5.9	4.7	5.0	1.3	7.7	875
Pine Ridge Road	NC 794	0	2000/april	original	0.9	0	0	0	0	0.2	0.47	6.2	1034
Leila Mae Lane	OD 623	0	2000/may	original	4.2	5.3	5.7	5.3	4.9	5.1	0.86	7.4	1079
Green Briar Trail	HO 241	25	1994/feb	original	6.3	5.2	6.5	5.8	4.9	5.7	0.65	7.4	565
Scarlet Oak Trail	HW 842	25	1994/sept	original	18	20	19.1	20	17.5	18.9	1.2	6.6	604
Meadow View Lane	ID 824	25	1995/feb	original	29	31	33.1	33.1	28.2	30.9	1.5	7.7	627
Emily Anne Drive	HO 248	74	1994/jan	original	2.5	NT	NT	NT	1.9	2.2	2.3	NT	NT
Colleen Court	OE 824	76	2000/july	original	1.9	1.6	1.4	2	0	1.4	3.9	8.2	672
Witzel Avenue	ID 532	80	1994/dec	reconstructed	35	42	38.5	41.5	31	37.6	4.4	7.4	685
9th Street	HW 851	81	1994/sept	replacement	35	39	36.4	38.5	35.4	36.9	1.8	6.3	612
Woodridge Drive	LW 780	81	1997/aug	original	39	34	41.7	44.1	37.9	39.3	4.1	7.8	678
Emily Anne Drive	LK 372	81	1997/march	reconstructed	84	67	62.5	52.3	42.3	61.6	6.9	6.5	661
Forte Road	MC 381	82	1997/nov	replacement	2.1	1.9	2.1	1.8	2.2	2.0	2	7.7	530
Sheboygan Street	LT 966	83	1997/april	original	1	0	0	0	0	0.2	0.02	7	1154
Forest View	LT 974	83	1997/april	original	42	47	44.4	42.2	45.2	44.2	4.6	6.5	677
Countryside Court	MC 344	85	1997/sept	original	37	38	43	41.7	28.4	37.6	4.9	6.9	680
Pine Ridge Road	NR 856	85	2000/jan	original	21	23	24.5	22.9	22.1	22.7	2.5	6	650
Amy Jo Drive	KS 445	86	1996/feb	reconstructed	25	17	20.9	13.4	9.4	17.1	15	7.3	652
Emily Anne Drive	MG 231	87	1998/sept	replacement	2	1.7	1.1	0	0	1.0	3.8	7.4	536
Westbreeze Drive	MG 232	87	1998/sept	replacement	5.6	14	14.4	13.3	13.5	12.2	3	7.2	656
Leonard Point Road	NR 875	87	2000/feb	original	14	12	13.5	13.4	15.3	13.6	0.39	7.8	559
Marquis Road	NX 703	88	2000/jan	replacement	5.6	3.8	4.8	3.9	3.3	4.3	2.4	7.9	907
Danbe Road	ID 574	92	1995/feb	reconstructed	45	31	5.8	15.9	7.9	21.1	5	7.7	837
Westmoor Road	NN 725	95	1999/sept	replacement	0	0.8	1.1	0	1.1	0.6	4.4	7.8	661
Meadowview Lane	KS 461	96	1996/march	reconstructed	17	15	16.4	16.5	15.4	16.1	1.3	7.5	550
Westbreeze Drive	ID 536	100	1994/dec	reconstructed	24	17	21.5	19.4	18.3	20.0	1.8	6.9	637
Leonard Point Road	OE 806	105	2000/july	original	0	1	1.2	0	0	0.4	0.15	7.8	801
Westbreeze Drive	LL 499	111	1996/dec	replacement	32	28	33.9	31.9	34.4	32.0	5	7.6	657
Green Briar Trail	NN 786	123	1999/oct	replacement	12	11	12.1	11	10	11.2	4.2	7.4	627
Westbreeze Drive	OL 542	124	2000/sept	replacement	71	20	29.1	26.2	23.8	34.0	8.6	7.6	695
Honey Creek Road	MS 144	125	2000/may	original	11	8.7	8.5	10.4	10.4	9.8	2.6	7.9	642
Green Briar Trail	OP 734	149	2001/jan	replacement	NT	19	12.7	18.1	19.6	17.4	NT	7.9	656
Forte Road	OL 569	162	2000/oct	replacement	3.9	4	2.5	1.7	2.2	2.9	4.4	6.1	701
Amy Jo Drive	FP 834	210	1994/feb	reconstructed	0.8	1.2	2.9	0	0	1.0	4.5	8.1	610
Emily Anne Drive	FP 851	213	1994/march	reconstructed	0	4.7	0	0	NA	1.2	5.7	8.2	602
Bellhaven Lane	MY 031	limestone	1999/jan	original	2.9	2.2	3.3	1.9	1.7	2.4	2.2	8.1	835
Omro Road	OD 664	limestone	2000/june	original	2.7	2.7	4.5	2.8	4.3	3.4	0.63	7.4	744

**Well casing refers to the length of solid steel casing extending into the St. Peter Sandstone formation. Therefore, any wells listed as "0" in the well casing column would have casing terminated in the Galena Platteville formation, but are drawing water from the St. Peter Sandstone formation. The two wells listed as "limestone" wells have casing that terminates in the Galena Platteville formation and draw water from the Galena Platteville. The lower borehole does not penetrate the St. Peter Sandstone.

Arsenic Results Key

<10 ppb

10 - 49 ppb

> 50 ppb

NA = Not Available

NT = Not Tested

ppb = parts per billion

ppm = parts per million

CON = Conductivity

Results For Wells Outside of Town of Algoma

STREET NAME	TOWNSHIP	WUWN	WELL CASING (feet into StP)	CONSTRUCTION DATE	WELL TYPE	ARSENIC (ppb)						IRON (ppm)	pH (S.U.)	CON (umhos/cm)
						Nov. 2000	Apr. 2001	Aug. 2001	Dec. 2001	Mar/Apr. 2002	Avg. Conc.	Nov. 2000	Apr. 2001	Apr. 2001
Kiely Way	Clayton	NN 769	14	1999/oct	original	**11**	**11**	**10.9**	**12.1**	**12.8**	**11.6**	0.67	7.9	414
Mielke Road	Osborn	HK 462	23	1994/may	original	**29**	**27**	**29.4**	**31.1**	**25.3**	**28.4**	26	6.8	908
Weelaunee Drive	Utica	IG 250	23	1995/july	original	0	NT	NT	NT	0	0.0	0.74	NT	NT
Apollo Court	Clayton	MS 148	24	2000/may	original	0.8	1.1	1.4	0	0	0.7	0	7.1	895
CTY RD GG	Vinland	HY 713	26	1994/oct	original	**12**	**12**	**13.4**	**14.9**	**14.3**	**13.3**	1.7	6.5	667
Kortney Lane	Osborn	KL 509	39	1995/nov	original	0.7	NT	NT	NT	0	0.4	1.9	NT	NT
Grandview Road	Winchester	MR 920	64	1998/aug	replacement	0.7	0.9	0	0	0	0.3	1.7	7.8	648
STH 168	Seymour	HL 480	82	1994/sept	replacement	1.4	NT	NT	NT	0	0.7	1.6	NT	NT
Center Road	Clayton	NK 899	87	1999/nov	replacement	**14**	**19**	**15**	**22.3**	**11.7**	**16.4**	7.2	7.7	647
Elm Road (A)*	Angelica	MY 397	93	1999/feb	replacement	**570**	**1100**	NA	NA	NA	**835.0**	240	3.5	NT
Elm Road (B)*	Angelica	OP 469	115	2001/april	replacement	NA	NA	1.6	1.3	3.2	2.0	NT	NT	NT
Oakwood Avenue	Clayton	KQ 450	94	1996/june	replacement	**150**	**150**	**127**	**156**	**157**	**148.0**	3.4	7.8	717
French Road (A)*	Osborn	FO 118	114	1993/march	reconstructed	**10**	NA	NA	NA	NA	**10.0**	3.5	NA	NA
French Road (B)*	Osborn	OQ 983	195	2001/april	replacement	NA	5.2	2.9	1.7	2	3.0	NA	6.8	649
Quarry Road	Center	HN 392	130	1994/june	replacement	4.6	NT	NT	NT	3.4	4.0	17	NT	NT
Mayflower Drive	Grand Chute	HL 209	183	1994/feb	replacement	**30**	**27**	**27.6**	**25**	**23.8**	**26.7**	11	7.7	783

*The wells on Elm Road and French Road were both replaced during the course of this study.
In both cases, well (A) would be the first well that was included in the study and well (B) was the second well that completed the study.

Arsenic Results Key
<10 ppb
10 - 49 ppb
> 50 ppb
NA = Not Available
NT = Not Tested
ppb = parts per billion
ppm = parts per million
CON = Conductivity

Results For Wells From Both Studies: 1998* and 2004

STREET NAME	TOWNSHIP	WUWN	CASING (ft. into StP)	CONSTR. DATE	WELL TYPE	ARSENIC CONCENTRATION (ppb) **										
						Apr-97	Jun-97	Sep-97	Jan-98	Avg.	Nov-00	Apr-01	Aug-01	Dec-01	Mar/Apr-02	Avg.
Mielke Road	Osborn	HK 462	23	1994/may	original	28	33	35	32	32	29	27	29.4	31.1	25.3	28.4
Weelaunee Dr.	Utica	IG 250	23	1995/july	original	0	0.9	1.1	0	0.5	0	NT	NT	NT	0	0.0
CTY RD GG	Vinland	HY 713	26	1994/oct	original	11	10	8.9	10	10.0	12	12	13.4	14.9	14.3	13.3
Kortney Lane	Osborn	KL 509	39	1995/nov	original	0	0	0.9	1.1	0.5	0.7	NT	NT	NT	0	0.4
Emily Anne Dr.	Algoma	HO 248	74	1994/jan	original	4	2.6	2.5	1.9	2.8	2.5	NT	NT	NT	1.9	2.2
Witzel Avenue	Algoma	ID 532	80	1994/dec	recon.	43	33	39	26	35.3	35	42	38.5	41.5	31	37.6
STH 168	Seymour	HL 480	82	1994/sept	repl.	7.3	2.6	3.8	2.6	4.1	1.4	NT	NT	NT	0	0.7
Danbe Road	Algoma	ID 574	92	1995/feb	recon.	53	64	37	51	51.3	45	31	5.8	15.9	7.9	21.1
Quarry Road	Center	HN 392	130	1994/june	repl.	2.4	3.2	2.3	2.5	2.6	4.6	NT	NT	NT	3.4	4.0
Mayflower Drive	Grand Chute	HL 209	183	1994/feb	repl.	69	63	53	NT	61.7	30	27	27.6	25	23.8	26.7
Amy Jo Drive	Algoma	FP 834	210	1994/feb	recon.	5.1	6.6	5.8	4.9	5.6	0.8	1.2	2.9	0	0	1.0
Emily Anne Dr.	Algoma	FP 851	213	1994/march	recon.	1.6	2.1	1.3	0.7	1.4	0	4.7	0	0	NA	1.2

*** *A Study of Well Constructed Guidance in Northeast Wisconsin,* Weissbach et al, 1998**

**** See Table V in document for further analysis**

Arsenic Results Key
<10 ppb
10 - 49 ppb
> 50 ppb
NA = Not Available
NT = Not Tested
ppb = parts per billion

Appendix G

2004 WDNR Well Construction Recommendations

in Arsenic Advisory Area

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

September 10, 2004

To: Wisconsin Licensed Well Drillers

Subject: Establishment of "Special Well Casing Pipe Depth Area"
Outagamie County & Winnebago County (Entire area of both Counties)

Dear Wisconsin Licensed Well Driller:

A "Special Well Casing Pipe Depth Area" has been established for all of Outagamie and Winnebago Counties, Wisconsin. Attached is a memo describing this new "Special Well Casing Pipe Depth Area." This area has been established due to naturally-occurring arsenic contamination problems affecting many wells in these two counties. This new "Special Well Casing Pipe Depth Area" includes the entire two county area and replaces the former "Arsenic Advisory Area" established by the Department in 1993. This new area also supersedes the four previously established arsenic "Special Well Casing Depth Areas" in these two Counties.

As of October 1, 2004, Private wells must be constructed, grouted and disinfected according to more stringent standards within this "Special Well Casing Pipe Depth Area" -- as described in the attached documents. This area has been established under the provisions of s. NR 812.12(3) and is designed to reduce the possibility that new wells constructed or reconstructed in these two counties produce water with significant concentrations of arsenic.

Consuming water containing high concentrations of arsenic has been shown to pose a significant hazard to human health. These new required construction standards for these two counties will involve alternate drilling methods and construction specifications that are more stringent than the minimum requirements of the State Private Well Code (NR 812). Wells constructed or reconstructed in much of the area of these counties will have to be cased & cement grouted down to at least the top of the Cambrian Sandstone. In some of the eastern parts of these counties there will also be an alternate option to construct wells in a manner that will allow the use of the shallow Galena-Platteville Dolomite Aquifer.

Consultation with the Department's Northeast Region's Drinking Water Program Staff is recommended -- prior to construction -- to help determine if a proposed well will meet these more stringent standards.

Sincerely.

Mark F. Putra, R.S. Chief
Private Water Systems Section
Bureau of Drinking Water & Groundwater

Attachment
cc: Statewide Drinking Water & Groundwater Program Staff
Outagamie County Health Department
Winnebago County Health Department

“Special Well Casing Pipe Depth Area” (Arsenic Area)
Outagamie County (Entire County) and
Winnebago County (Entire County)

A “Special Well Casing Pipe Depth Area” is herewith established for the entire area of both Outagamie and Winnebago Counties. Within these counties new wells must be constructed to more stringent standards as indicated below.

The establishment of this “Special Well Casing Pipe Depth Area” is based on the potential that new wells constructed in this area to minimum Private Well Code (NR 812) specifications would be at significant risk to arsenic contamination.

This “Special Well Casing Pipe Depth Area” is established under the Department’s authority provided by Section NR 812.12(3), Wis. Adm. Code (State Private Well Construction & Pump Installation Code). This area replaces the former “Arsenic Advisory Area” -- established by the Department in 1993 – and includes the entire two county area. This new “Special Well Casing Pipe Depth Area” also supersedes the four previously established arsenic “Special Well Casing Depth Areas” within these two Counties.

EFFECTIVE DATE

This “Special Well Casing Pipe Depth Area” is effective on October 1, 2004.

LOCATION

This “Special Well Casing Pipe Depth Area” includes all of Outagamie County and all of Winnebago County, Wisconsin. **(If you plan to construct wells in these two counties, the department will provide, upon request, maps describing the well construction options and the minimum casing/cement grout depth settings.)**

CONTAMINANT

Naturally occurring inorganic arsenic.

WELL CASING DEPTH SETTING AND GROUTING REQUIREMENTS

Option A: This Option is allowed east of the lines* delineated on the ‘Option A’ map. Within the gray shaded areas east of the line on this map, Galena-Platteville Dolomite bedrock wells may be constructed using the standard Private Well Code specifications of Sections NR 812.10 to NR 812.22. However, this option may only be used if the total well depth is not greater than 80 feet. (The Galena-Platteville Dolomite is the first bedrock layer in the eastern part of Outagamie & Winnebago Counties.) Within this Option A area, wells deeper than 80 feet may be allowed, but only with specific Department approval.
* The boundary lines delineating the areas where Option A wells are allowed are listed in detail in the appendix at the end of this document.

If the open bedrock drillhole is accidentally extended deeper, then it shall be back-filled with neat cement grout up to a level at least 10 feet above the base of the Galena-Platteville formation. In order to accomplish this back filling, a tremie pipe shall be extended to the bottom of the hole and the cement grout shall be pumped in using an approved pressure method according to the requirements of s. NR 812.26.

Note: West of the Option A boundary lines there are some areas, although small in extent, where the variations in the geology also make the shallow Galena-Platteville Dolomite bedrock well option possible. Such areas may become evident from a review of available well construction reports in a given area where you are planning to drill a well. Within these areas a specific Department approval is required for each well for this shallow bedrock option.

Option B: Any private well constructed within this "Special Well Casing Pipe Depth Area" -- and not constructed according to Option A -- shall be constructed with cement-grouted steel casing extending at least to the top of the Cambrian Sandstone. **(**Within this area the Cambrian Sandstone lies below either the St. Peter Sandstone or below the Prairie du Chien Dolomite, whichever happens to be present beneath any particular well site.)
The department has prepared 36 individual Township maps for these two counties. Upon request the Department will provide these maps.
For Option B wells, the minimum depth of the upper-enlarged drillhole, the casing and the cement grout is designated by the number provided within each quarter section on these maps.
Although unlikely, these minimum casing depth designations may not extend all the way down to the Cambrian Sandstone. In any case, the casing and cement grout shall be extended at least to the top of the Cambrian Sandstone.*
(Often the first 10 to 15 feet of the Cambrian Sandstone is reddish in color and can produce water with a high iron content. You may want to also extend the casing and cement grout through this top reddish layer.)
* Note: When planning the construction of a well in this two county area, it is important to review Well Construction Reports -- for the area around the specific well site. This will help you determine the depth to the top of the Cambrian Sandstone at a proposed well site. If you have difficulty in this determination, please consult with the Department's Northeast Region Drinking Water & Groundwater Specialists in Green Bay. They will assist you in this determination.

Existing bedrock wells may also be reconstructed within this area. Before contracting to reconstruct a well, you **must** first verify if the well was constructed to meet the well code requirements -- for location and construction -- that were in effect at the time of original construction. Once you have verified code compliance, you may reconstruct the well by installing a liner -- at least two inches smaller in diameter than the primary casing diameter -- provided the liner is extended from the ground surface down to at least the top of the Cambrian Sandstone. (Reconstruction of an existing bedrock well will likely necessitate first extending the lower open bedrock drillhole into the top of the Cambrian Sandstone.) The liner shall be installed according to the requirements of s. NR 812.21(1) and shall be sealed in place with neat cement grout using an approved pressure method according to the requirements of s. NR 812.20.

SPECIAL WELL CONSTRUCTION & DISINFECTION SPECIFICATIONS & METHODS

Within this "Special Well Casing Pipe Depth Area", private wells shall be constructed with alternate construction methods and more stringent specifications for construction, grouting and disinfection. Wells shall be constructed, cement-grouted and disinfected according to the following specifications:

1. For 6-inch diameter wells, the upper-enlarged drillhole shall have a minimum diameter of 8 ¾ inches rather than the minimum 8-inch diameter. For larger diameter wells, the upper-enlarged drillhole shall be at least 2 inches larger in diameter than the nominal diameter of the permanent well casing pipe.

2. The upper-enlarged drillhole shall be constructed using rotary mud-circulation methods or cable-tool methods. Rotary-air methods may **not** be used for this purpose. The size of the mud pit shall have a volume large enough to provide for efficient removal of drill cuttings. Further, a centrifuge sand separator shall be installed with the mud circulation system to help remove sand-sized drill cuttings that may contain arsenic-laden sulfide minerals.

3. Water used to mix the drilling mud slurry shall have a pH between 7 and 8.5. If the pH is below 7, it shall be slowly treated with soda ash to achieve a pH within this range.

4. The cement grout shall be ordered from a commercial concrete company, shall be ordered free of aggregate, and shall have a slurry density of at least 15.2 lbs./ gallon, but preferably should have a density of 15.6 lbs./gal. The grout density shall be measured with a mud balance at the well site.

5. The grout shall be adequately screened to remove any unexpected aggregate before it enters the grout pump hopper.

6. The cement grout shall be pumped into the annular space using either the "Bradenhead" or the "Grout Shoe" method and the grouting operation shall be done in a manner according to the requirements of s. NR 812.20.

7. At completion of the grouting procedure, the grout shall flow out the top of the annular space with the same density as the grout being pumped from the hopper and shall have a density of at least 15.2 lbs./gal. The grout density shall be measured with a mud balance.

8. The cement grout shall be allowed to set for at least 24 hours before the construction of the lower bedrock drillhole is commenced.

9. To avoid introduction of air (and oxygen) into the aquifers, the lower open bedrock drillhole shall be constructed using rotary-mud or "rotary-wash" drilling methods, i.e. rotary water-circulation methods. Rotary-air methods may **not** be used for this purpose. As an alternative, the lower drillhole may be constructed using cable-tool methods or with other drilling methods provided they do not inject air into the aquifer and are approved by the Department.

10. Upon completion of the well, an approved additive-free liquid chlorine (sodium hypochlorite) product shall be used to disinfect the well. Dry calcium hypochlorite products (granular or pellet type) may **not** be used. The chlorine solution may **not** have a concentration greater than 100 milligrams per liter (mg/l), and **not** more than 30 minutes of contact time in the well. After this time has elapsed, the solution shall be thoroughly flushed out of the well with water, **not** with air.

JUSTIFICATION FOR ESTABLISHING THIS "SPECIAL WELL CASING DEPTH AREA"

Justification for establishing this "Special Well Casing Pipe Depth Area" includes the following:

8. Much of area of Outagamie and Winnebago Counties is within the former "Arsenic Advisory Area" established by the Department for northeastern Wisconsin in 1993. Within these counties many wells are contaminated with arsenic. Of the private well sampled as part of the Town-based sampling survey conducted in these counties between the years 2000 and 2003, 779 of 3,905 wells (19.9 %) had arsenic concentrations exceeding 10 parts per billion[@]. Samples from some wells contained arsenic in thousands of parts per billion. These wells have some of the highest arsenic concentrations ever found in the world. [@][parts per billion (ppb) is comparable to micrograms per liter (µg/l).]

9. Many well construction reports submitted for wells in this area indicate a "black sandstone" layer within the bedrock sequence. This dark layer indicates an arsenic-bearing sulfide mineral horizon in the upper layers of the St. Peter Sandstone. If the Department does not establish special well construction requirements for this area, most new wells constructed to minimum private well code standards would have a significant risk of producing water with arsenic concentrations exceeding the new health standard of 10 ppb.

10. Outagamie and Winnebago Counties are being rapidly developed with housing subdivisions. Many of these subdivisions have high-density lots. This rapid real estate development will likely necessitate the construction of many new closely spaced private wells. High concentrations of closely-spaced private wells -- constructed only to minimum Private Well Construction Code (NR 812) requirements -- would likely cause the arsenic contamination problems of this area to get significantly worse. If special casing depth requirements were not established, most new wells would likely be constructed to minimum code requirements. Such wells would have bedrock drillholes open to the mineral-laden layer that can release arsenic into the groundwater. Operation of many closely spaced wells has the potential to lower the groundwater table of this area. Such a lowering can repeatedly expose the arsenic-bearing horizon to oxygen as the water table fluctuates across this layer. The Department has found -- through research and experience -- that arsenic problems are especially prevalent in areas where there are high concentrations of wells constructed only to minimum casing depth settings. Establishment of this "Special Well Casing Pipe Depth Area" and the resultant construction of new wells with much deeper cement grouted casing settings will greatly reduce the chances new wells will produce water with elevated concentrations of arsenic.

11. Between the years 1993 and 2000 ninety wells were constructed according to Department recommended special construction specifications within the "Arsenic Advisory Area". More than eighty-five percent of these wells were successful according to the previous arsenic health standard of 50 ppb. In 2001 these special construction & disinfection methods were modified to be more effective. These modified specifications further increase the chances that new wells produce water free of arsenic. Since these updated recommendations went into effect, 131 wells have been constructed according to these more stringent specifications. Only eight of these 131 wells (6 %) have arsenic concentrations exceeding the new arsenic health standard of 10 ppb. (None of these wells had concentrations exceeding the old

standard of 50 ppb.) Even though these wells were not successful at a criterion of 10 ppb, all of them produce water with arsenic concentrations low enough to allow Department of Commerce approved treatment equipment to be effective and efficient at removing the arsenic.

12. Over a lifetime, the risk of developing cancer from consuming water containing arsenic at concentrations exceeding 10 ppb are very high compared to potential risks from other water contaminants. At the present time, scientific estimates of the risk of developing cancer from drinking the water from these wells over a lifetime is approximately three in 1,000.

13. Other health effects of consuming water contaminated with arsenic can include blood vessel damage, hypertension, nerve damage, diabetes, anemia, digestive problems and changes to the texture & color of the skin.

14. This new "Special Well Casing Pipe Depth Area" includes the former "Arsenic Advisory Area". Within this area the Department had recommended that new wells be constructed to the more stringent well construction and disinfection specifications. In addition, the Department has required more stringent well construction and disinfection specifications for wells in four previously established "Special Well Casing Pipe Depth Areas" located within these two counties. These stringent well construction specifications have been successful in providing new wells that produce water with low concentrations of arsenic. These stringent standards will not be a new concept for the residents of this area or for the Licensed Well Drillers who have constructed wells to these standards in these counties.

APPENDIX

Construction of wells according to Option A -- i.e. Galena-Platteville Dolomite bedrock wells no deeper than 80 feet -- is allowed within this "Special Well Casing Pipe Depth Area", but only in the gray-shaded areas on the Option A map.* This gray area is described as follows:

- **Outagamie County:**
  East and South of a line delineated by the following:
  -- Highway 47 (S. Memorial Drive) starting at the Winnebago Co. line & extending north;
  -- Highway 47 (N. Richmond Street) extending north through downtown Appleton to Hwy 41;
  -- U.S. Highway 41 extending east to intersection with N. Meade Road.;
  -- N. Meade Road extending north to intersection with E. Apple Creek Road;
  -- E. Apple Creek Road extending northeast to County Highway E;
  -- County Highway E extending northeast to intersection with Co. Hwy S in Freedom;
  -- County Highway S extending east from Freedom to intersection with McCabe Road;
  -- McCabe Road extending north to intersection with Bain Road;
  -- Bain Road extending east to intersection with Co. Highway U on the Brown Co. Line.
  <u>And</u> East & North of a line delineated by the following:
  -- U.S. Highway 54 extending west from the Brown Co. Line to Cooper Road;
  -- Cooper Road extending north to Pearl Road;
  -- Pearl Road extending west to Smith Road;
  -- Smith Road extending north and then west to County Highway Y;
  -- County Highway Y extending north to Corput Road;
  -- Corput Road extending north to County Highway VV
  -- County Highway VV extending west to Isaar Road;
  -- Isaar Road extending north to the Shawano County Line.
- **Winnebago County:**
  East and south and of a line delineated by the following:
  -- State Highway 44 extending northeast to County Highway N;
  -- County Highway N extending east to Clairville Road;
  -- Clairville Road extending north to 9th Street Road;
  -- 9th Street Road extending east to U.S. Highway 41;
  -- U.S. Highway 41 extending northeast to County Highway G;
  -- County Highway G (and its eastern extension) east to Lake Winnebago.

* <u>Note</u>: Within this gray-shaded area, Option A type wells deeper than 80 feet may be allowed, but only with specific Department approval.

Appendix H
Details of Physical Testing

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1. Physical Testing of "Failed" King Well (UWN MG428)
(September, October, and November 2000)

The "King well," named after a previous owner, is located in the northwest corner of the Town of Algoma, Township 18N, 16E, Section 7, Winnebago County. It was one of the first replacement wells that WDNR discovered was failing shortly after construction, and turned out to be a very frustrating problem for the owners. To date, there have been a total of three wells constructed on this property due to high arsenic levels. Basic physical testing consisting of pressure testing and observation of the casing with a down-hole video camera, was conducted on the second well in an attempt to try to determine why this replacement well "failed;" i.e., why levels of arsenic, while low immediately after construction, increased over time to where they greatly exceeded the standard.

Background and Geology

The original (first) well on this property was constructed in August of 1992. It was constructed by air rotary methods by Wagner Brothers. It had an 8" hole to 42 feet and 6" hole to 125 feet. The log indicates red clay to 12 feet, clay and sand to 20', clay, sand and gravel to 23', Limestone to 65' and Sandstone to 125'. Static water was listed at 69' with a pumping level of 79' at 15gpm for 1 hour. It was Unique Well Number FT489. There is no available data on the arsenic concentrations in this well other than it was high enough to require replacement for the property transfer.

Bill Van De Yacht constructed the second new well in 1998 (MG428) a short distance from the original well. The geology according to the Well Construction Report is essentially the same. The total depth was 162' with 6" casing to 147'. The upper drill hole was drilled using mud rotary and it is assumed, given the year of construction, that the lower borehole was drilled using air. The well was first grouted using the Bradenhead method (bottom up), but problems developed in the lowest part of the well. The drillers then switched to tremie pipe and continued with grouting. At some depth, the driller blew a pipe due to caving formation. Static water was at 70' and the pumping level was 120' at 30 gpm for 1 hour. Arsenic levels were in the 2 ppb range when tested in June of 1998. A follow-up sample early that fall was the same. In January of 1999, the King family noticed a dramatic increase in iron. A water company was contacted and an arsenic sample was taken in April of that year. The first sample
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came back at 334 ppb As. Two days later it was 181 ppb. Since then, multiple samples were taken, and concentrations bounced between 130 – 320 ppb.

The following analytic results indicate water quality has generally deteriorated, yet no real fingerprint was apparent:
Fe 7-9 ppm, Mn 100-260 ppm, Ni 200-510 ppb, SO_4 41-47 ppm, Zn 8-11 ppb, Co240 ppb, Conductivity 580, Gross alpha 25 pCi/L, Gross Beta 11 pCi/L, Ra226 3.8 pCi/L, Ra 228 5 pCi/L, U 0.53 pCi/L, As +3 has been 3.5 and 5.2 % of total, Colloidal As was measured at 4.7 and 11.8%.

Since the King's participated in WDNR's Arsenic Water Treatment Demonstration Project, their raw water was speciated to determine levels of +3 valance arsenic vs. +5. The fact that very little of the As was in the +3 state implies that it is not transport. (Other wells where migration has seemed likely have had much higher percentages of As+3.) However the zinc and nickel were relatively low for direct oxidation, and we know that the sulfide cement horizon in the area often has high levels of nickel associated with it. The trigger for oxidation would have been air drilling and/or disinfection at the time of construction. The homeowner reported that no additional chlorinating has been done. The option of a secondary (lower) source is not likely in the area within the mid-portions of the St. Peter. It was very clean and the only evidence of sulfides in the area is at the contact with the Glenwood formation. Thus, the sudden deterioration approximately six months after construction seemed to indicate that the grout, and ultimately the casing, had failed. This seemed to make sense, given the admitted problems that the driller had grouting due to the collapse of the sandstone. The casing joint was within several feet of the static water level. The Kings agreed to keep the well open and available for testing.

The well is located in the subdivision located in the northwestern portion of the town of Algoma called Mueller Plat II, less than two blocks north of many other wells with high concentrations of arsenic, including the well which reported 12,000 and 15,000 ppb arsenic. Both UWN FP851 and FP834 were replaced with deep liners (see below).

The geology of deep wells in the area is:

EQ906/FP851(replaced with liner)
0-12 Red Clay

12-25 Gravel and Sand

25-77 Limestone

77-155 Sandstone

155-190 Red Shale

190-195 Black Shale

195-260 Red Shale and Limestone

260-300 Pink and White Sandstone

300- 324 Hard Red Sandstone

324-380 Pink and White Sandstone

CZ587/FP834 (previous owner Wentzel)

0-15 Red Clay

15-25 Sand and Gravel

25-80 Limestone

80-220 Sandstone

220-262 Red Shale and Limestone

262-305 Pink and White Sandstone

305-325 Hard Red Sandstone

325-365 Pink and White Sandstone

EQ907/LK372 (also replaced with a liner)

0-15 Red Clay

15-23 Sand and Gravel

23-72 Limestone

72-243 Sandstone

The first two wells were reconstructed by drilling out and lining to approximately 290'. Both have had low levels of As although Wentzel has been as high as 18ppb. The last well (LK372) was lined off to 155'. It has had increasing As, with levels ranging widely between 80 and 400 ppb, and higher percentages of As+3 than other speciated wells in the area.

<u>King Replacement:</u>

Since two deeply lined wells very nearby had maintained low levels of arsenic over a period of several years, it was decided to follow that example and case to around 300 feet. As for a new well versus a reconstruct, it was decided that it was best to start over with a whole new (third) well as far away from the old well(s) as possible, since a casing and grout failure could be the cause of the second well failing, and once this geo-chemical reaction was triggered, it could possibly migrate vertically and horizontally.

Testing of the “failed” well:

It was generally agreed that it was very important to try to determine **why** the King’s replacement well, which was ostensibly constructed according to DNR Arsenic Special Casing Guidance, failed after only 6 months. This information was vital to the Department of Natural Resources’ determination of guidance to well drillers in the Arsenic Advisory Area, and the ability to set future policy. (For example, should the Special Casing “Advisory” in the Arsenic Advisory Area be changed? Should it be made a “Special Casing “Requirement?”) Testing the integrity of the grout, while important, (particularly since the well drillers indicated they had problems grouting), was not deemed to be economically nor technically feasible. Thus, the only affordable options were to test the casing for holes/leaks. This testing consisted of video taping the inside of the casing, and pressure testing.

A pressure test was conducted on 8/1/00 by Van DeYacht Well Drilling and DNR. A gasket-type well seal was installed at the top of the well, and nitrogen gas was pumped in. (Attempts to video the well prior to conducting the pressure test failed due to torque arresters which necessitated pulling the pump up 20+ feet to get the camera out.) So the pressure test was set up. On the third try, the driller got a good seal and began to pressure up the well. Pressure rose steadily, but then began to slow down. The pressure finally reached 16 PSI. Once input was stopped, the pressure began to fall and stabilized at about 15.67 PSI. (NOTE: A more accurate gauge would have been helpful, and was recommended for future pressure tests of failed arsenic wells.) The 16-PSI is equivalent to 36.9 feet of depression of the water table. The .33 PSI loss is a recovery of .76 feet or 1.14 gallons. Immediately after the test, the pump was run, and the water discharge was clear. The homeowner reported that after we left, the water ran very cloudy and noticeable amounts of sediment built up in the toilets and tanks.

There are several possible explanations for the test results.

1) There is a hole somewhere (e.g., at the pitless adaptor) between the top of the casing and the final water level of approximately 104 feet, although the presence of such a hole could not be seen through the murky water with the camera. The entrance velocity of the hole was such that it took 15+ psi to drive air out.

2) There is a hole at 104 and that is why the pressure never rose above 16 PSI. This hole then might explain the sand pumping, although the 1-hp pump would pull fast enough to pump sand up from the lower hole.

An additional observation from the video attempt was that the casing was in good shape and not very rusted as reported in other wells. This may be explained by migration of the arsenic into the well below the water table. With a discharge below the water table and below the fluctuation level of the water under normal pumping conditions, the generation of acid gas would be much less and corrosion would be kept down. This is consistent with the chemical data and the lower nickel concentrations, since in migration the arsenic will travel faster and farther than the other metals.

The well was video taped by Ken Meyer of Luisier Well Drilling on September 1, 2000. The joint at 103.5 feet looked to be slightly out of line with either a gap on one side or at least incomplete penetration of the weld. Inspection with the pump running in the hole did not show inflow at the joint.

A final test of the well casing integrity was done at the time of abandonment. The abandonment was done in stages. The lower borehole was filled with bentonite chips and allowed to sit for 4 days to let the bentonite fully hydrate and seal the casing. The water in the casing was then pumped out to a level of 129 feet below the top of the casing. Once the water was removed from the casing, the casing was video taped again to look for leaks. Again, there were no obvious leaks.

One week later (November 21, 2000) the water level was measured again and was still at the same level, which leads to the assumption that the integrity of the casing was still good.

The pump installer measured the depth of water in the casing again on December 1st, and found it to be unchanged. The well was then completely permanently abandoned on December 1st.

The new (third) well was completed on October 26, 2000. Arsenic levels in this third well have to date been consistently less than 5 ppb.

<u>Summary and Conclusion</u>

Overall there were too many uncontrolled variables for this simple physical testing of the King well to be conclusive.

1. The well was video taped 3 times, twice with water in it, and once after the lower borehole was abandoned and the water was pumped out of the casing. The significant amount of debris dislodged from the casing and floating in the water made it very difficult to see if there were any cracks or holes in the casing. We paid particular attention to the joints at the top of the St. Peter (sulfide mineralization) where one would suspect the greatest weakness in the casing. The video of the casing after the water was pumped out was also inconclusive; i.e., there *appeared* to be a slight darkening at the 103-foot joint, but it did not look like an *obvious* hole or crack.

2. The pressure test was also inconclusive. One would have expected the pressure to drop more than 1/3 of a pound if there was a hole in the casing. Instead, the pressure dropped a third, and then stabilized for the next 25 minutes with no further loss of pressure indicated on the gage. It is *possible* that there was a slight fissure or hole in the casing (most likely at the joint) but that it "healed" itself by having material entering back into the hole from outside the casing once the pressure was generally equalized. Another puzzling aspect of the pressure test was the inability to get more than 16 PSI of air into the well.

Consequently, the physical testing conducted on the King well neither proves, nor completely disproves, the possibility of loss of casing integrity. Again, we did not have the technology to check the grout.

Physical testing conducted by: Dave Johnson, DNR; Troy Simonar, Tom Van DeYacht, and Andy Van De Yacht of Van DeYacht Water Wells; Kelley O'Connor, DNR; Liz Heinen, DNR; and Ken Meyer of Luisier Well Drilling.

2. Physical Testing of Burgess Well (UWN MA816)

(Summer, 2001)

Background

WDNR drinking water staff became aware of this replaced well failing in 2001.

The failed replacement well was pressure tested and video logged on July 27, with similar methodology and similar inconclusive results as the King Well.

The Burgess original well was constructed in 1988 with a total depth of 140 feet and 41 feet of casing. The static water level on his original well in 1988 was 79 feet; on August 22, 2001 it was 60 feet. This well was drawing its water from the Galena Platteville and St. Peter Sandstone formations. After noticing changes in water quality, the family had their well tested which revealed arsenic levels exceeding the standard (e.g., 81 ppb on 6/19/97).

Replacement well

On 7-22-97, a new well was drilled (MA816) with a total depth of 322 feet and 188 feet of casing. Static water level on this replacement well on August, 27, 2001 was 87.4 feet. Comparing this with the static water level on the original well a week prior indicates significant downward gradients. This well draws water from the Prairie du Chien, Jordan, and St. Lawrence formations. The original well was not abandoned after the new well was drilled.

Test results for the first year showed arsenic levels in the acceptable range, but then the numbers gradually increased:

8-05-97	No detect (less than 1.5 ppb)
5-26-98:	1 ppb
6-16-99	12 ppb
3-05-01:	112 ppb
5-10-01	175

It was postulated that perhaps the fact that the original well was not abandoned might be at least a partial cause of the increase in arsenic in the replacement well over time, due ostensibly to downward and horizontal migration. This theory is supported by the fact that the static water level of the original well was 60 on August 22, 2001, and static water level on the replacement well taken just one week later was 87.4. The distance between the original well and the replacement well is about 10 feet. Time of travel calculations between the old and new well indicate that it would take between 1.7 and 4.6 years for contaminated from the old well under the measured gradient to reach the new well. This matches the timeline where sample results indicated increasing levels of arsenic and eventually iron levels.

Results and Conclusions

The replacement well MA816 was video logged and pressure tested on July 27, 2001. Results were inconclusive. The first well was then abandoned. To date, the family is using the MA816, but not for drinking or cooking.

3. Physical Testing of Hendzel Well (WUWN MY 397)

(Spring, 2001)

Background

This family has had three wells drilled on their property, which is located in the Town of Angelica in eastern Shawano County. After their original well showed high levels of arsenic (1500 ppb on 9-28-98, and 667 ppb on 10-22-98), a second well was drilled on 2-4-99. This replacement well, located in the Town of Angelica, had arsenic detected at 570 ppb during the first round of sampling. The replacement well was itself replaced in April 2001 with WUWN OP469. This well has high iron, but to date, acceptable levels of arsenic.

Geology

WUWN MY397, the first replacement well, had 133 feet of casing and 160 feet of total depth.
The Well Construction Report revealed the following geology:
Feet:
0-10’ Clay
10-25 Sand
25-40 Limestone
40-160 Sandstone
So this well was drawing its water from sandstone. Static water level was 40 feet below the surface.

Physical Testing

It was decided to conduct some basic physical tests on the first replacement well. On April 19, 2001 (two weeks after their third well was drilled), a downhole video camera was inserted into the well. No holes or bad joint welds could be seen. A pressure test was also conducted and showed no significant change in pressure.

This second well (first replacement well), MY397 was partially abandoned (approximately up to the bottom of the casing) to determine if groundwater was leaking through the casing. During this ‘free-drain test’, the water level inside the casing was checked twice and pumped over a 4-week period. There was virtually no measurable groundwater in the well, so it appears that the casing was not leaking. The well was then completely abandoned.

Results and Conclusions

Again, these tests were inconclusive in determining why the first replacement well failed. One problem with the testing of this well occurred when the driller abandoned the lower borehole. Unfortunately, he misjudged the amount of bentonite needed to abandon just the lower borehole and the bentonite expanded into the casing approximately 28 feet. Thus, if there was damage to the lower 28 feet of the casing, this would not be possible to ascertain based on this test. As with the other wells, we did not have the ability to check the efficacy of the grout in these wells.