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A Study of Well Construction Guidance for Arsenic Contamination in Northeast Wisconsin

Black formation cuttings and borehole fluid returns upon penetrating the St. Peter Sandstone mineralized zone.

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Study of Well Construction Guidance for Arsenic Contamination in Northeast Wisconsin

by

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Wisconsin Department of Natural Resources
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Project ID.: 127

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Background/Need: Naturally occurring arsenic in groundwater at levels above the Drinking Water Standard (DWS = 50 µg/L) in East Central Wisconsin has resulted in the identification of an Arsenic Advisory Area (AAA). In a relatively large geographic area covering several counties, a guidance document is in place that recommends 80 feet of casing extending through the upper portion of the Ordovician St. Peter Sandstone Formation.

Objectives: The objectives of the study were threefold: 1) to evaluate if the Wisconsin Department of Natural Resources (WDNR) recommendations for well construction within the AAA provide adequate protection from the presence of arsenic in drinking water above the drinking water standard, 2) to determine if arsenic concentrations increase over time, and 3) to examine if, when faced with a contaminated well, it is best to replace it with a new one or to reconstruct the existing well with a liner sealing off the arsenic bearing zone.

Methods: Seventy-four private wells constructed during a two-year period (1994 - 1995) in the AAA within Outagamie and Winnebago counties were sampled during four different seasons (Spring, Summer, and Fall of 1997, and Winter of 1998). Upon appropriate purging of pressure tank systems, samples were collected from untreated water faucet sources and were immediately preserved with nitric acid. Seasonal samples were also collected from three monitoring wells constructed during an earlier investigation in the AAA near a site with extreme arsenic well water contamination. Samples were analyzed for arsenic and iron at the State Laboratory of Hygiene. In addition, pH and conductivity were recorded at the time of sample collection.

Results and Discussion: It is hypothesized that a chemical reaction similar to acid mine drainage occurs when a mineralized zone at the contact of the St. Peter Sandstone (SS) and the Galena Platteville (GP) is oxidized. Oxygen reaches this contact either by regional recharge, vertical leakage through the GP, or directly by oxygenation of the water in the open borehole either by air rotary construction of the well or a fluctuating water table. The series of chemical reactions that lead to the presence of iron and arsenic in the groundwater are believed to start with the oxidation of iron (II) to iron (III) which in turn dissolves pyrite and causes a general acidification of the water near the mineralized zone. The acidic conditions further liberate dissolved arsenic into groundwater thereby contaminating drinking water supplies. In addition to East Central Wisconsin, the occurrence of elevated arsenic in drinking water supplies has been recorded in West Bengal, Argentina, Taiwan, Northern Mexico, and the states of New York and Washington.

The long term health concerns associated with arsenic in groundwater are not well known. However, some researchers believe ingested arsenic may increase the risk of skin cancer. Exposures to high levels of arsenic in groundwater in Taiwan appear to increase the occurrence of cancer of the liver, lung, bladder, and kidney. A report on the effects of arsenic in groundwater in West Bengal, India, described the presence of various arsenical skin lesions such as hyperkeratosis and gangrene. In New York, researchers report impairment of bone marrow function, diarrhea, vomiting, liver toxicity, fatigue, and tingling in extremities from exposures to arsenic.

A review of several hundred well construction reports for 1994 and 1995 indicated that the majority of well drillers in Outagamie and Winnebago counties did not follow the AAA guidance. Based on the sampling results, 9.5% (7 of 74) of the wells included in the study produced water that exceeded the DWS on at least one occasion. The highest number of exceedances were recorded for wells in Algoma Township having less than five feet of casing through the upper sandstone layer. The percentage of exceedances observed during this study is approximately three times higher than that seen in other studies of arsenic in Wisconsin. Perhaps this is because wells chosen for this study were known to have penetrated the SS whereas previous studies sampled a more random distribution of wells.

The results of over 300 water samples collected during this study do not show a strong correlation between arsenic and expected seasonal groundwater fluctuations. Statistical analyses using least squares regression showed that trend lines did not fit the data very well (low R^2 values), however the trend line directions were consistent between all four collection events and between various correlations. In other words, the trend lines in all graphical presentations of the data do show a correlation between increasing arsenic concentrations, decreasing pH, and increasing conductivity and iron concentrations. Finally, there didn't appear to be any rise in arsenic concentrations in the 74 wells or the three monitoring wells over the span of the research project. However, it should be kept in mind that the sample population is quite small in comparison to the thousands of wells constructed in the AAA. Despite the results of the study, ongoing contacts between WDNR drinking water staff and homeowners in the AAA indicate that arsenic concentrations in numerous wells do appear to increase over time.

Recommendations:

Results of the study appear to indicate that the recommended 80 feet of casing through the upper portion of the SS may not be necessary in the AAA; a recommendation of **40 feet** of casing would probably suffice. Additionally because of the prevalence of problems, 40 feet of casing should be a *requirement*, rather than a *recommendation* in the Towns of Algoma (Winnebago County) and Osborn (Outagamie County). Local health agency staff who routinely sample and monitor arsenic levels in drinking water wells should be in close contact with WDNR to alert staff about new problem areas. Drillers should be educated about encountering black or gray sandstone (easily seen as darker water flowing from the borehole during drilling or as dark cuttings). This likely indicates that a mineralized, arsenic bearing stratum has been penetrated and additional casing should be installed to seal this zone. Certain chlorination aids (used for iron problems) should be discouraged because chlorine may act as an oxidizer and accelerate the oxidation process that liberates arsenic. Future research should be conducted to determine if pump depth has an effect on the concentration of arsenic in groundwater.

Related Publications:

Burkel, 1993, Arsenic as a Naturally Elevated Parameter in Water Wells in Winnebago and Outagamie Counties, Wisconsin, MS Thesis, UW Green Bay

Pelczar, 1996, Groundwater Chemistry of Wells Exhibiting Natural Arsenic Contamination in East Central Wisconsin, MS Thesis, UW Green Bay

Simo, et al., 1996, Geologic Constraints on Arsenic in Groundwater with Applications to Groundwater Modeling, UW Madison Groundwater Research Report

Simo, et al., 1996, Stratigraphic and Geochemical Controls on Mobilization and Transport of Naturally Occurring Arsenic in Groundwater, UW Madison, Alumni Newsletter

Key Words:

Arsenic, St. Peter Sandstone, Groundwater, Northeast Wisconsin, Drinking Water Wells

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Final Report:

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

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1 Introduction

The presence of arsenic in groundwater at levels above the current Wisconsin Administrative Code NR140 enforcement standard (ES) and the United States Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL) of 50 $\mu g/L$ ($\approx$ 50 ppb) has been detected in private drinking water wells throughout specific areas of East Central Wisconsin. This phenomenon is believed to be naturally occurring due to chemical processes taking place in the bedrock aquifer from which the wells draw water. For purposes of this report, Drinking Water Standard (DWS) will refer to both the ES and MCL. Please note, EPA is currently evaluating the existing DWS of arsenic with an expected determination in January 1, 2001.

The arsenic occurrence was first identified in 1987 during a routine feasibility study for a proposed landfill location in the township of Vinland, Winnebago County. Drinking water wells in the vicinity of the proposed site were sampled for background parameters to develop baseline data on groundwater quality in the area. Arsenic was detected in five out of eight wells above the NR140 preventive action limit (PAL) at 5 ppb. Sampling of more wells in the general area detected a similar trend and it was concluded that a natural source was likely. It is hypothesized that chemical reactions similar to acid mine drainage occur when a mineralized zone at the contact of the St. Peter Sandstone (SS) and Galena Platteville (GP) is oxidized. Oxygen reaches this contact either by regional recharge, vertical leakage through the GP, or directly by oxygenation of the water in the open borehole either by air rotary construction of the well or a fluctuating water table. The series of chemical reactions that lead to the presence of iron and arsenic in the groundwater are believed to start with the oxidation of iron (II) to iron (III) which in turn dissolves pyrite and causes a general acidification of the water near the mineralized zone. The acidic conditions further liberate dissolved arsenic into groundwater thereby contaminating drinking water supplies.

Coincidently in 1987, a well in the township of Clayton (further north in Winnebago County) had arsenic at a level of 75 ppb (Burkel, 1993). In February 1990, the Wisconsin Department of Natural Resources (WDNR) was contacted by a well owner in the Township of Osborn in Outagamie County. The well had started to show signs of declining water quality including metallic tasting water, deteriorating water supply system, and clothes that literally fell apart after being washed. The problems began a year earlier when a pump was replaced and a packer was removed from the well. After several failed attempts to remedy the problem, the WDNR was contacted. Initially, a low pH ($\leq$ 2.5) and high levels of various metals (Cr, Cu, Fe and Pb) were identified in the groundwater; further sampling detected arsenic at 3,200 ppb.

These detections of high arsenic levels in groundwater initiated further research sponsored by the WDNR. To determine the distribution and frequency of the problem, 1,037 groundwater supply wells were sampled in Outagamie and Winnebago counties during 1991-1993 (Burkel, 1993). Of those wells sampled, 185 (17.8%) exceeded 10 ppb and 37 wells (3.6%) exceeded the DWS. This study, among others, led to the development of a so-called *Arsenic Advisory Area* (AAA) which includes most of Outagamie and Winnebago counties. This document is referred to as the *Well Driller Guidance for Well Construction in Areas with Naturally Occurring Arsenic Water Quality Problems*. When new wells that draw water from a particular aquifer are constructed within the AAA, drillers are encouraged to construct the wells with additional casing in an effort to seal off the arsenic bearing stratum.

In order to verify the effectiveness of this current construction guidance, Pelczar (1996) sampled six drinking water wells constructed in various ways and three monitoring wells. These wells were sampled every three months over a two-year period (1994-1996) at seven different arsenic-impacted sites. Five of these wells had been reconstructed or replaced and these measures seemed to alleviate the water quality problems. The sixth drinking water well, which had not undergone any remedy except for lowering the pump, continued to supply water of poor quality including high levels of arsenic (320-630 ppb). The results indicated that replacing a well with enough casing to seal off the arsenic-bearing stratum, or alternately reconstructing a well to seal off this zone, was effective in reducing arsenic concentrations in affected wells.

Arsenic at elevated levels has also been identified in groundwater in other parts of the United States such as Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, Oklahoma, Oregon, and Washington (Welch et al., 1988; Bhattacharya et al., 1997; Robertson, 1989; Wagner et al., 1979). Globally, arsenic tainted groundwater has also been discovered in Bangladesh, Chile, India, Mexico, Argentina, and Taiwan (Bhattacharya et al., 1997; Chatterjee et al., 1995; Das et al., 1995; Cebrián et al., 1983; Concha et al., 1998; Bagla and Kaiser, 1996).

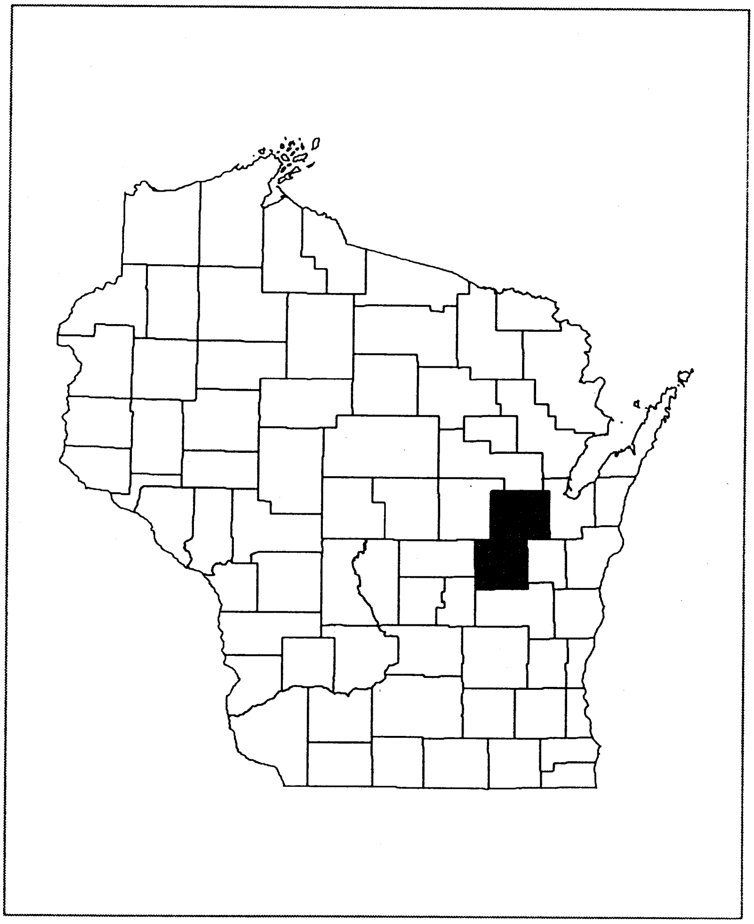

Figure 1.1: Location of Outagamie (top) and Winnebago (bottom) counties in Northeast Wisconsin.

1.1 Scope of Work

Currently there is well construction guidance available for the Arsenic Advisory Area (AAA) which includes most of Outagamie and Winnebago counties (see Figure 2.1 and Appendix A). This guidance advises well drillers to construct wells to withdraw water from either the upper Galena-Platteville unit or the lower Prairie du Chien unit. If this is not possible and the St. Peter Sandstone (SS) formation is penetrated, the guidance recommends that the top 80 feet of this unit are cased off. This measure has proven to be successful, at least so far, in avoiding arsenic contamination in newly constructed wells. The locations of Outagamie and Winnebago counties are shown in Figure 1.1.

The main objectives of this study are to determine if WDNR recommendations for the AAA (see Figure 2.1) are adequate and if arsenic concentrations in well water in the area increase over time for both impacted wells and the general region. Previous analytical groundwater data from this area have indicated that high arsenic concentrations can also be associated with high iron concentrations. Therefore, this study also examined the relationship between arsenic and iron to determine if there was a direct correlation.

2 Background

The following section gives a description of the regional geology of the study area as well as a discussion of the general chemistry and health concerns associated with arsenic.

2.1 Geology of Study Area

The surficial geology in the area consists of glacial drift and lake deposits of Wisconsin age glaciation which can vary in thickness from one foot to over two hundred feet. The bedrock which supplies drinking water for the majority of the private wells in the area is identified as predominantly Ordovician in age. Generally the Galena-Platteville (GP) dolomite formation is encountered immediately below the glacial deposits. It is comprised of very resistant crystalline dolomite with numerous sandy and silty zones. This dolomite unit serves as both a leaky confining unit capping the underlying St. Peter Sandstone as well as a separate aquifer with sufficient yields for private wells. Groundwater tends to move through the GP in fractures and solution channels. This means that the GP may or may not produce enough water for a private well depending on if the well intersects any water bearing fractures.

The St Peter Sandstone (SS) formation underlies the GP unit and consists of soft, friable, well sorted sandstone. Deposited on a highly eroded surface, the SS varies considerably in thickness over short distances. The formation is highly permeable and is an important source of water for wells in eastern Wisconsin and Illinois. However, well yields vary considerably from well to well. The Prairie du Chien group is located below the SS unit and is comprised of dolomite and sandstone formations. Both formations supply some water to private wells, however, as a whole, the group is not considered a productive unit. Below the Prairie du Chien group lies the Cambrian sandstone unit which is predominantly comprised of medium- to fine grained, well sorted, poorly to well cemented quartz sandstone. The Cambrian sandstone is the most important regional aquifer and is the principal source of water for most industrial and municipal water supply wells (Elliot, 1994). For a more detailed description of East Central Wisconsin geology as it relates to arsenic, please refer to Simo et al. (1996a) and Pelzcar (1996).

2.2 Groundwater Chemistry of Study Area

The occurrence of elevated levels of arsenic in drinking water supplied by private wells appears to be both a local and a global problem. Table 2.1 lists selected arsenic levels in groundwater in the United States and other parts of the world. Please note that the **highest** naturally occurring arsenic concentrations in groundwater, identified globally through literature review, was located in the current study area.

***Table 2.1:** Selected arsenic concentrations (in ppb) identified in groundwater at different locations.*

Arsenic concentration (ppb)	Location	Reference
<0.6-12,000	Northeast Wisconsin, USA	Burkel, 1993
9,000-10,900[a]	New York, USA	Franzblau and Lilis, 1989
<10-33,000[a]	Washington, USA	Frost, et al., 1993
50-3,700	West Bengal, India	Chatterjee, et al., 1995
~ 200	Northern Argentina	Concha, et al., 1998
10-1,752	Southwest Taiwan	Chen, et al., 1992
160-590	Northern Mexico	Cebrián, et al., 1983

[a]: *The high arsenic levels in Washington and New York are believed to be caused by a continuous releases from mine tailing piles leaching to groundwater.*

Various studies performed in Northeast Wisconsin appear to indicate that the high arsenic levels in certain private wells are caused by chemical reactions occurring naturally in the SS aquifer. A mineralized layer containing high levels of pyrite (FeS_2) with arsenic attached to its crystal structure is present primarily in the top part of the SS. Where the SS is absent, this mineralized zone also appears to be present at the base of the GP formation. Although never fully researched, it is postulated that this mineralized zone originated from metallic brines that were formed during sedimentation of the Lake Michigan Basin during the latter part of the Paleozoic Era. These hydrothermal brines flowed upslope and mineralized at the contact between the SS and GP formations. This created the arsenic bearing zones. Generally these deposits are easily identified visually as a dark gray layer at the contact.

The chemical reactions that lead to the presence of arsenic in drinking water are believed to be similar to what occurs during acid mine drainage (Manahan, 1994):

$$2FeS_2(s) + 2H_2O + 7O_2 \rightarrow 4H^+ + 4SO_4^{2-} + 2Fe^{2+}$$

The next step in the process is the oxidation of iron(II) to iron(III) which can be catalyzed by a variety of bacterial strains depending on the pH level:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

Iron(III) further dissolves pyrite:

$$FeS_2(s) + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

These reactions generate a more acidic environment, thus changing the arsenic from a solid to a dissolved form, causing the release of arsenic to the groundwater. Note that arsenic is not included in any of the above chemical reactions because the exact chemistry of dissolution is unknown.

The introduction of oxygen which is necessary to induce the oxidation of the pyrite and hence cause the release of arsenic to groundwater can generally occur in three ways: either by regional recharge, vertical leakage through the GP formation, or simply through oxygenation of the groundwater within the borehole from contact with the atmosphere (Simo et al., 1996b). According to Simo et al. (1996b), the latter suggestion is considered the most probable. Thus, the construction of a well open to this mineralized zone can cause a chain of events which eventually results in well water contaminated with arsenic.

So far, the problems with naturally occurring arsenic in well water have mainly been confined to Outagamie and Winnebago counties in East Central Wisconsin. This has led to the development of an Arsenic Advisory Area (AAA), as mentioned earlier, for most of the townships in Outagamie and Winnebago counties. In this area, well owners are advised to take special precautions when constructing drinking water wells (see Appendix A). The Arsenic Advisory Area is outlined in Figure 2.1.

Several years after the designation of the AAA, wells in one area of western Brown County (north of Outagamie County) began experiencing similar arsenic contamination problems. However, the area was subsequently served by municipal water, therefore, the AAA was not expanded.

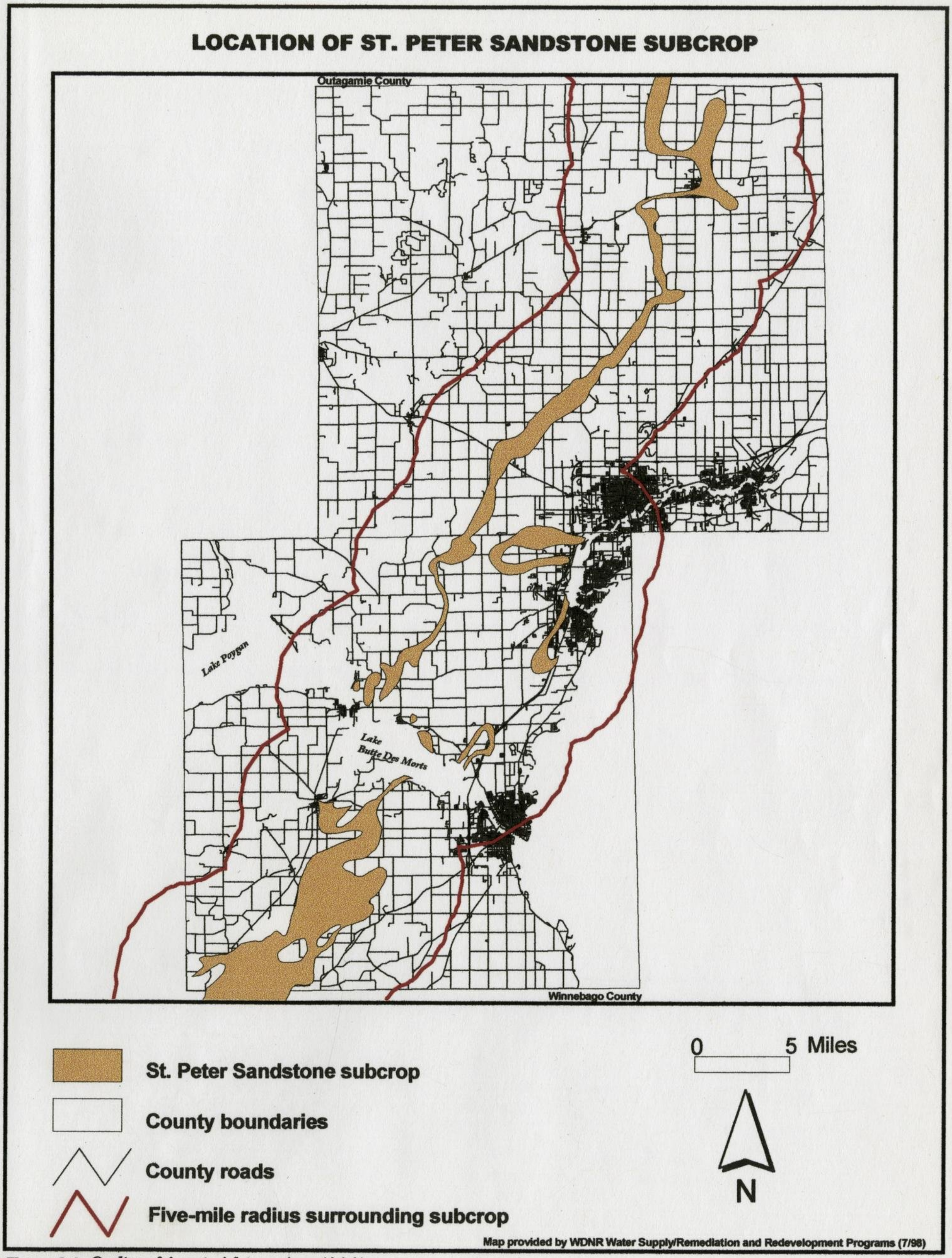

Figure 2.1: *Outline of Arsenic Advisory Area (AAA).*

2.3 Arsenic in the Environment

Elemental arsenic is not a metal, but rather a metalloid. This means that the compound displays both metallic and non-metallic properties such as low thermal and electrical conductivity (EPA, 1992b). Arsenic does not occur by itself in a natural environment. Depending on pH and redox-potential, it most commonly appears in natural systems as arsenate (AsO_4^{3-}), arsenite (AsO_2^-), or arsine gas (AsH_3). Arsenic can therefore exist at three different valence stages of +V, +III, and -III respectively, but is generally associated with other compounds such as hydrogen or oxygen. Arsenate is the most common arsenical compound found in soil or groundwater. Arsenite is more mobile in groundwater due to its higher solubility in water (4-10 times higher solubility than arsenate) (EPA, 1992b; EPA, 1997). Furthermore, arsenic in surface waters can also occur in different methylated compounds which are produced by various organisms and the human body as part of a detoxification process (methylated arsenic is itself less toxic than arsenate is less toxic than arsenite) (Chatterjee et al., 1995).

Commercially used arsenic is usually recovered as a byproduct at mining facilities. The most important arsenical compound for industrial use is arsenic trioxide (AsO_3). Currently neither this compound nor any other arsenic compound is produced in the United States. The major manufacturer of arsenic trioxide in 1991 was China. Also, no arsenic is recovered at industrial facilities (mainly smelting operations in the past), due to strict federal and local regulations on both air emissions and worker exposure to inorganic arsenic. The estimated arsenic demand in the United States has been fairly constant at 19,640 metric tonnes (total arsenic) in 1971 and 21,600 tonnes in 1991. In 1991, major uses of arsenic were in wood preservation (14,300 tonnes with cromated copper arsenate (CCA) as the most common compound) and agricultural chemicals (5,000 tonnes). Minor amounts of arsenic (arsenic acid) is also used in the glass industry to disperse bubbles in certain types of glass products, and in the electronic industry (EPA, 1992a). At wood preservation facilities, the most commonly used metal containing wood preservative is CCA. Some of these facilities that previously used arsenic containing compounds to prolong the useful life of wood products are now in the process of being remediated through the US EPA Superfund Program (EPA, 1997).

Naturally occurring arsenic is usually associated with marine sedimentary rock, mineral deposits, weathered volcanic rock, fossil fuels, or geothermal areas (Korte and Fernando, 1991). Arsenic can be released from these sinks due to either anthropogenic activity or a general change in pH and/or redox-potential in the subsurface environment.

2.4 Health Concerns

The general public can be exposed to arsenic in various ways such as by air, drinking water, food (especially seafood), and some beverages. Cigarette smokers may also be exposed to arsenic in tobacco, but the chemical constituents are unknown at this point (Chen et al., 1992). Trace amounts of arsenic may even be essential for the human body. Arsenic deprivation has been described in certain farm animals (Pelczar, 1996). When arsenic is ingested in the human body the majority is excreted through the urinary tract within a relatively short time frame but some accumulation will occur in various organs such as the liver, kidneys, lungs, spleen, bone, muscle, and skin tissue. Long term exposure will lead to arsenic accumulation in hair and nails (Pelczar, 1996).

Acute poisoning can occur when ingesting doses of more than 100 mg of arsenic (Manahan, 1994) and inhalation of arsine gas has been known to cause cancer. The long term health effects of ingesting small amounts of dissolved arsenic through tainted drinking water, for example, are not clear. Some researchers believe that ingested arsenic may cause skin cancer. This was shown through often-cited studies in Taiwan where elevated rates of skin cancer were identified in a human population exposed to elevated levels of arsenic in well water (Tseng et al., 1968; Tseng, 1977). However, the US EPA has raised doubts about the validity of this study (EPA, 1988).

A study conducted in Outagamie and Winnebago counties in Northeast Wisconsin, indicated that residents ingesting more than 50 μg arsenic per day for more than a year appeared to have a significantly higher risk of getting skin cancer than residents exposed to lower levels (Haupert et al., 1996). This study involved 1,623 residents that were recruited in a campaign recommending that people within the AAA have their water tested. Participants were chosen that had lived in the area for more than one year. Health questionnaires were filled out before they received sample bottles for well water testing. Thus participants did not know the levels of arsenic in their water before answering health questions. This study seems to support the Taiwan study indicating that elevated arsenic concentrations in drinking water are associated with increased skin cancer rates. It is currently thought that ingesting inorganic arsenic inhibits the ability of certain enzymes to repair sun-damaged skin.

Chen et al. (1992) found a significant dose-response relationship between the levels of naturally occurring arsenic in drinking water and the mortality of different cancers. Exposure to high levels of arsenic appeared to increase the occurrence of cancers of the liver, lung, bladder, and kidney for a population on the southwest coast of Taiwan. The study did not identify any significant difference in gender response to arsenic exposure.

Groundwater laced with arsenic has also been discovered in West Bengal, India, at concentrations of up to 3,700 ppb (Bagla and Kaiser, 1996; Chatterjee et al., 1995; Das et al., 1995). In this case, it is also believed to be a naturally occurring phenomenon where dissolved arsenic is released to the aquifer due to a change in the general redox regime. Nearly 200,000 people are exhibiting various arsenical skin lesions such as hyperkeratosis (hardened patches of skin that may develop into cancers) and even gangrene. Arsenic speciation performed on groundwater samples indicated that trivalent arsenic (arsenite), which is the most toxic species, was present at about 50% of the total arsenic level.

Franzblau and Lilis (1989) presented a case study on the effects of ingesting high levels of arsenic in drinking water (9,000-10,900 ppb). The report described a married couple in the State of New York who had moved into an older home with a newly installed well. An arsenic speciation test performed on a groundwater sample revealed that the predominant species (75%) was pentavalent arsenic (arsenate), which is the least toxic form of arsenic. The well was located in a mining area and it was hypothesized that the elevated arsenic levels in groundwater were caused by a release from old mine tailings. Rock samples obtained from these tailings revealed arsenic levels of up to 32,100 mg/kg. This couple experienced impairment of bone marrow function, gastrointestinal symptoms such as diarrhea and occasional vomiting, evidence of liver toxicity, fatigue, and tingling in certain extremities. The wife also developed a rash and the husband experienced intermittent confusion and disorientation. The wife seemed to suffer the worst symptoms and also had a slower recovery which is probably because she appeared to consume more well water than the husband. This episode happened over a period of several months and the symptoms were probably due to the exposure to extremely high levels of arsenic in the potable water source. Feinglass (1973) reported similar health effects for workers exposed to arsenic levels up to 21,000 ppb in drinking water in western Minnesota. The arsenic levels in this case are not believed to be caused by a naturally occurring phenomenon but rather a release from an arsenical based grasshopper pesticide, buried in the soil as a means of disposal.

Based on the literature review, it is clear there are no definite conclusions as to what health effects the ingestion of inorganic arsenic through contaminated water may have on the human body. Generally, dermal contact with dissolved arsenic (i.e., showers) is not considered a health threat. More research on dose-response effects for different locations and populations is required to adequately define potential health concerns related to the ingestion of arsenic. It appears that the effects from long term exposure to arsenic in drinking water are far more severe in less developed countries than in the United States. At this time it is unknown if this is due to less nutritional food intake, different immune system response, or genetic variations. The ratio between arsenic (III) and (V) and the length of exposure may also play an important role in regard to the severity of the symptoms of arsenic exposure. Nonetheless, it appears that most of the health effects of ingesting dissolved arsenic can be reversed if an alternate water supply is provided.

3 Methodology

The purpose of this project was to assess the validity of WDNR recommendations for well construction to avoid arsenic contamination in the AAA. To do this, wells that were constructed according to guidance recommendations were compared with wells that were not constructed according to guidance. Wells compared were constructed during the same time period (January 1, 1994, through December 31, 1995) and in the same geographic area. In addition, groundwater quality was compared in wells that were either replaced or reconstructed because of arsenic contamination in the original wells. Reconstruction of a well usually includes deepening of the borehole and the installation of a liner within the original well. A diagram showing a well reconstructed using a liner is depicted in Figure 3.1. Note that the liner is sealed with grout within the original casing, a packer holds the grout in place and the pipe holding the pump is usually extended.

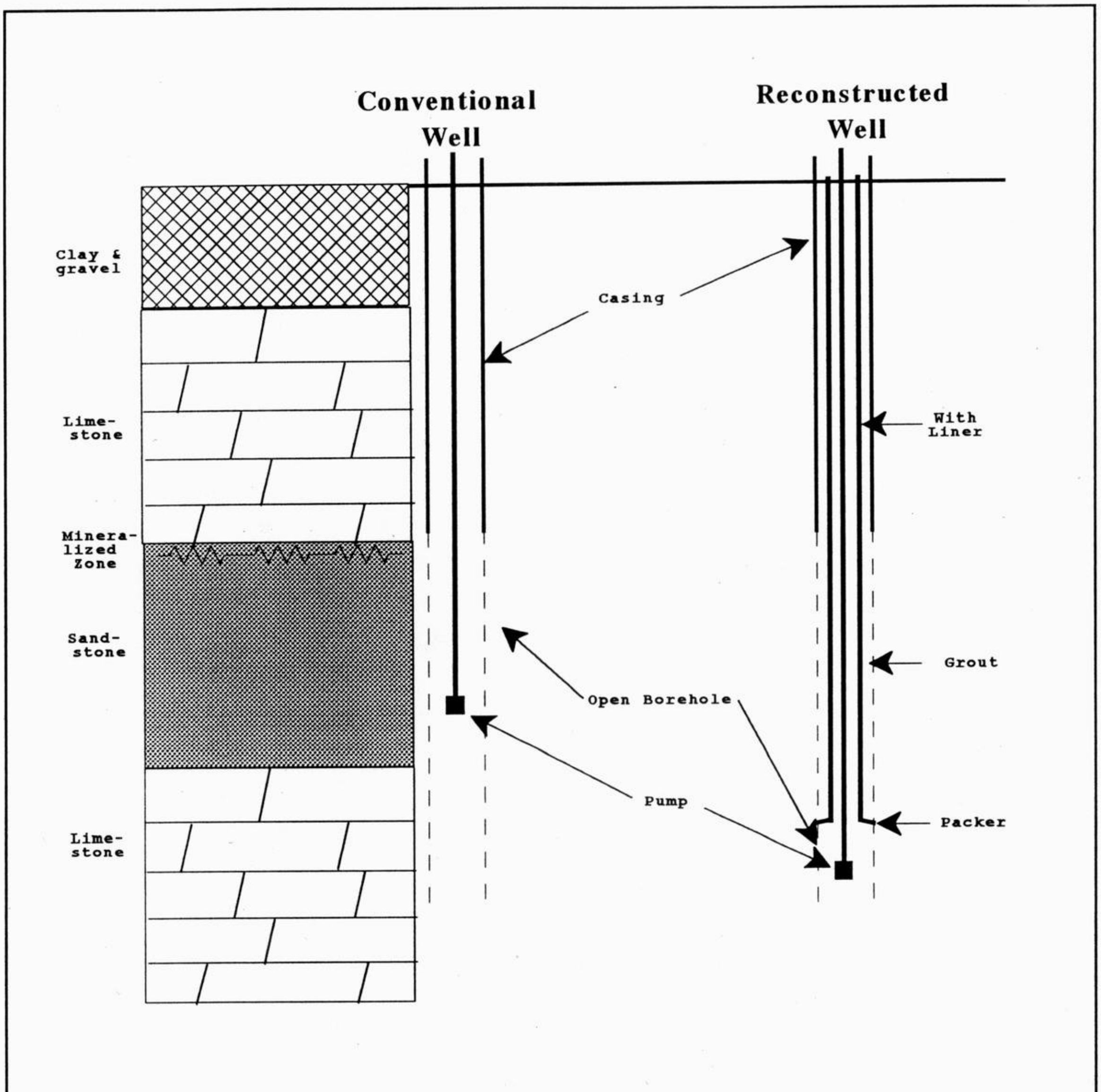

Figure 3.1: Sketch of a conventional well and a reconstructed well.

3.1 Identifying Wells in the AAA in Outagamie and Winnebago Counties

Tables 3.1 and 3.2 identify wells that were constructed or reconstructed between January 1, 1994, and December 31, 1995, in the Arsenic Advisory Area (AAA). Note that there are wells in townships in both counties that are not included in the AAA. The lists were tabulated using the commercial software FileMaker Pro 2.1. By using this database, it is possible to search all Wisconsin well construction reports (well logs) from January 1, 1988, to present. Well logs are required to be submitted to the WDNR. However, due to a variety of reasons, a number of construction reports may be missing from the database.

The original project proposal called for three groups of wells as described below (a total of approximately 75 wells):

- 25 wells constructed according to guidance (**Acc. guid.**)
- 25 wells not constructed according to guidance (**Non-guid.**)

- 5 wells reconstructed because of arsenic contamination (**Recon.**)
- 15 wells replaced because of arsenic contamination (**Replace.**)

- 3 monitoring wells

The first category (# of wells) in Tables 3.1-3.2 lists both the total number of wells and the number of wells in contact with the St. Peter Sandstone (SS). "Contact" indicates that the top part of the SS was penetrated during well construction. All the wells in the last four categories in the tables are in contact with the SS.

In the second column (Acc. guid.), the wells are categorized according to the amount of casing extending into the SS (see below). This is done because until February 1996, there was no clear definition of the meaning of a well "constructed according to guidance." Before February 1996, it was recommended to case off the upper portion of the SS. Currently, the guidance specifies that the upper 80 feet through the SS is to be cased off. This second category is therefore divided into these 3 subgroups respectively :

- 5-40 feet of casing in the SS (first number in Table 3.1 under Acc. Guid.)
- 41-79 feet of casing in the SS (second number)
- 80 or more feet of casing or cased entirely through the SS (less than 80 feet) and only drawing water from bedrock below the SS (third number)

The purpose of identifying the subgroups was, if possible, to determine whether 80 feet of casing through the top of the SS is an appropriate recommendation, or if the length of casing could be reduced and be equally effective yet save money for homeowners. The initial guidance did not specifically require any specific length of casing, it just recommended casing off the "top of the SS", although in some cases 80 feet was verbally recommended. The cutoff at five feet in the first subgroup was made because it was assumed that if there was five or more feet of casing through the SS, perhaps the driller was aware of the guidance and was trying to meet its intent.

Table 3.1: Wells encountered within the AAA in the target period for Outagamie County.

Townships	# of wells	Acc. guid	Non-guid.	Recon.	Replace.
Cicero (T.24N.-R.17E.)	16 /9/	- - -	9	-	(1)
West part Seymour/Northwest part Oneida (T.24N.-R.18E.)	29 /16/	- - 2	14	-	1+*, (1)
Northeast part Oneida/East part Seymour (T.24N.-R.19E.)	7 /2/	- - -	2	-	-
Black Creek (T.23N.-R.17E.)	20 /15/	- - -	15	-	-
Osborn/West céntral part Oneida (T.23N.-R.18E.)	32 /19/	2 - 2	15	-	-
East central part Oneida (T.23N.-R19E.)	19 /6/	- - -	6	-	-
Ellington (T.22N.-R.16E.)	49 /30/	1 1 1	27	-	-
Center (T.22N-R.17E.)	48 /25/	- 1 1	23	-	1+*, (1)
Freedom/Southwest part Oneida (T.22N.-R.18E.)	107 /43/	- - 5	38	-	(1* Iron)
Dale/South part Hortonia (T.21N.-R.15E.)	67 /64/	7 - -	57	-	(3)
Greenville (T.21N.-R.16E.)	157 /85/	1 - -	84	-	(1)
West part Grand Chute (T.21N.-R.17E.)	36 /15/	- - 1	14	-	1+*

// *Number of wells penetrating the top part of the SS*
- *No wells found belonging to that specific category*
() *Reason for replacement unknown — but it could be arsenic related*
\+ *Well replaced because of arsenic contamination in original well*
* *Replaced well was constructed according to guidance*

Example for Town of Center: A total of 48 wells were constructed of which 25 penetrated the St. Peter Sandstone aquifer. Of these 25 wells, none was cased from 5-40 feet, one was cased off anywhere from 41-79 feet and one had 80+ feet of casing. 23 wells were not constructed according to guidance. One well was replaced due to the presence of arsenic and installed according to guidance. One well was replaced for unknown reasons.

Table 3.2: Wells encountered within the AAA in the target period for Winnebago County.

Townships	# of wells	Acc. guid.	Non-guid.	Recon.	Replace.
Winchester (T.20N.-R.15E.)	20 /15/	2 - 2	11	-	(1*, 1)
Clayton (T.20N.-R.16E.)	52 /32/	- - -	32	-	-
Menasha (T.20N.-R.17E.)	4 /4/	- - -	4	-	-
Winneconne (T.19N.-R.15E.)	38 /31/	3 - -	28	-	-
West part Vinland (T.19N.-R.16E.)	12 /8/	2 - -	6	-	-
Neenah/East part Vinland (T.19-20N.-R.17E.)	46 /11/	- - -	11	-	-
North-west part Rushford/West part Omro (T.18N.-R.14E.)	19 /13/	2 - -	11	-	-
East part Omro/Northeast part Rushford (T.18N.-R.15E.)	26 /18/	- - -	18	-	-
Algoma (T.18N.-R.16E.)	128 /77/	4 2 7	64	3+*	3+*
Oshkosh (T.18-19N.-R.16-17E.)	23 /8/	1 - -	7	-	-
Nepeuskun/Southwest part Rushford (T.17N.-R.14E.)	11 /8/	2 - -	6	-	-
Utica/Southeast part Rushford (T.17N.-R.15E.)	18 /14/	3 1 2	8	(1*)	-
Nekimi (T.17N.-R.16E.)	23 /14/	- - 1	13	1+*	(1)

// *Number of wells penetrating the top part of the SS*
\- *No wells found belonging to that specific category*
() *Reason for reconstruction/replacement unknown — but it could be arsenic related*
\+ *Well reconstructed/replaced because of arsenic contamination in original well*
* *Reconstructed/replaced well was constructed according to guidance*

3.2 Procedure for Selecting Wells to Include in the Study

The townships were mainly selected in the AAA where the subcrop of the St. Peter Sandstone (SS) is known to be located. The most severe arsenic contamination would be expected to occur in the vicinity of the SS subcrop due to the possibility of continuous oxidation of the rock formation and the potential of wells penetrating this stratum. Hence, it is assumed that there potentially could be a production of acidic conditions which could induce a steady release of arsenic to the groundwater. Furthermore, some townships were selected to the east of the subcrop, where the SS is also located, but at a deeper depth, generally below the Galena-Platteville (GP) dolomite formation. The selected townships are listed in Table 3.3.

After identifying which townships to sample, an attempt was made to identify and verify the well owner information obtained from the well logs. The well owners were located using phone books and plat books and by phone calls. It was sometimes a very labor intensive task to find the current well owners due to limited information about some well locations and because of incorrect data on some well construction reports. Some of the wells not constructed according to guidance in most townships were omitted because of an abundance of these types of wells. The wells selected for this study are identified in Table 3.3.

On Thursday, March 13, 1997, letters were mailed to 154 well owners (sum of the two categories "Acc. guid." and "Non-guid." in Table 3.3). A total of 76 responses was received from well owners interested in participating in the study, which is a response ratio of approximately 50%. Seventy-two well owners were invited to participate in the study and the remaining four (the last four to respond) were informed that they would not be included. After two sampling rounds, WDNR was contacted by two well owners within the AAA who had been experiencing elevated arsenic levels in their drinking water. Due to the relevance to this study, these wells were included in the sampling efforts. Thus, the total number of wells sampled as part of this study was 74. The locations of the selected wells are identified in Figures 3.2 and 3.3.

Table 3.3: Number of wells included in the study. Please note that "# of wells" is the original number of wells identified in study area.

Townships	# of wells	Acc. guid.	Non-guid.	Recon.	Replace.
Outagamie County					
West part Seymour/North-west part Oneida (T.24N.-R.18E.)	29 /16/	- - 2	7	-	1+* (1)
Osborn/West central part Oneida (T.23N.-R.18E.)	33 /20/	2 - 3	7	1+*	-
Ellington (T.22N.-R.16E.)	49 /30/	1 1 1	10	-	-
Center (T.22N-R.17E.)	48 /25/	- 1 1	7	-	1+*
Freedom/South-west part Oneida (T.22N.-R.18E.)	107 /43/	- - 5	11	-	(1* Iron)
Greenville (T.21N.-R.16E.)	157 /85/	1 - -	5	-	(1)
West part Grand Chute (T.21N.-R.17E.)	36 /15/	- - 1	5	-	1+*
Winnebago County					
Winchester (T.20N.-R.15E.)	20 /15/	2 - 2	4	-	(1*, 1)
Winneconne (T.19N.-R.15E.)	38 /31/	3 - -	8	-	-
West part Vinland (T.19N.-R.16E.)	12 /8/	2 - -	4	-	-
Algoma (T.18N.-R.16E.)	137 /86/	5 2 11	17	8+*	3+*
Oshkosh (T.18-19N.-R.16-17E.)	23 /8/	1 - -	6	-	-
Nepeuskun/South-west part Rushford (T.17N.-R.14E.)	11 /8/	2 - -	4	-	-
Utica/South-east part Rushford (T.17N.-R.15E.)	18 /14/	3 1 1	5	-	-
Total # of wells in selected townships	**718 /404/**	**22 5 27**	**100**	**9+***	**6+***

// *Number of wells penetrating the top part of the SS*
- *No wells found belonging to that specific category*
() *Reason for reconstruction/replacement unknown — but it could be arsenic related*
+ *Well reconstructed/replaced because of arsenic contamination in original well*
* *Reconstructed/replaced well was constructed according to guidance*

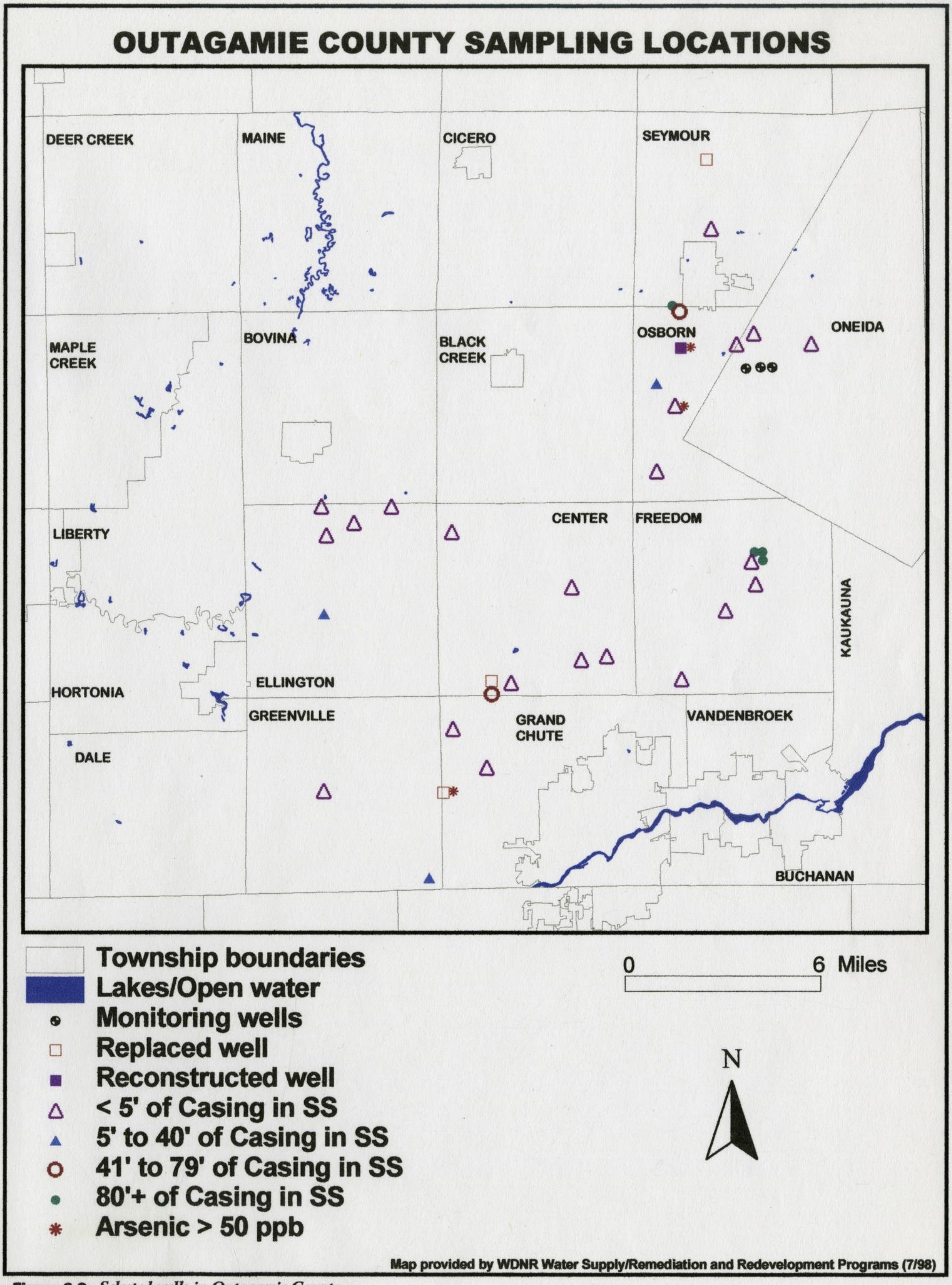

Figure 3.2: *Selected wells in Outagamie County.*

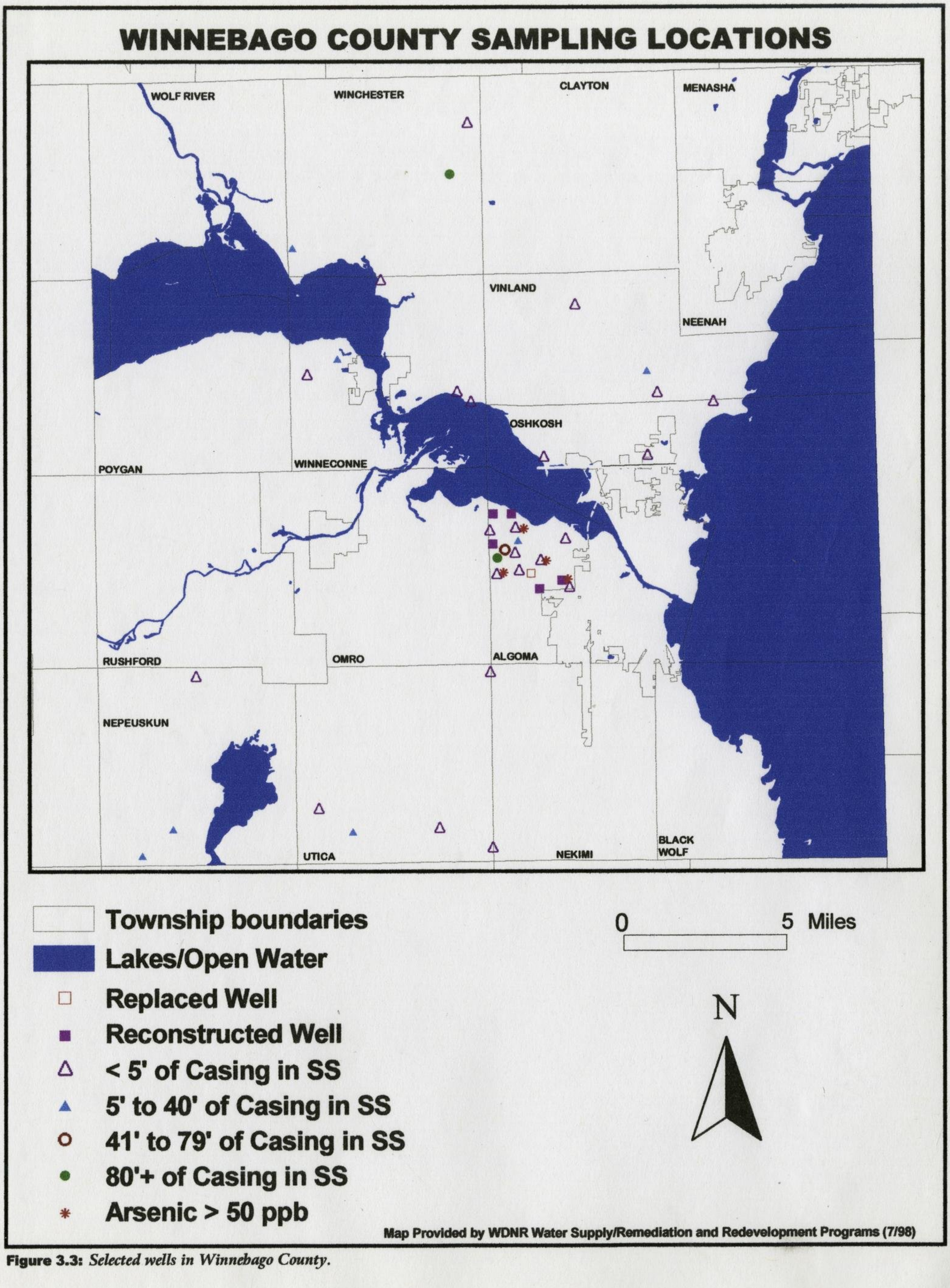

Figure 3.3: *Selected wells in Winnebago County.*

3.3 Collection of Groundwater Samples

An initial phone contact was made to verify that the well log matched each specific well using the Wisconsin Unique Well Numbers (WUWN). It was also discussed with the well owner where to collect a water sample prior to any pretreatment devices (e.g., water softener, iron filter, chlorination). Prior to each sampling round, each well owner was notified by phone that a sample was scheduled to be collected. Samples were collected during April, June, and September of 1997, and January of 1998. All samples were collected accorded to WDNR sampling protocol.

Before sample collection, the water was allowed to run (usually from outside faucet) for about ten minutes. This purged the distribution system and helped to avoid the collection of a stagnant water sample which may not have been representative of ambient groundwater conditions. This time interval was used to calibrate the pH-meter and check the operating parameters of the conductivity meter. Both meters were also checked prior to departure from the DNR office at the beginning of each sampling day.

Each water sample was collected in a 250 mL polyethylene bottle and immediately preserved with 2.5 mL (35%) nitric acid (HNO_3). None of the samples were field filtered because samples were collected from drinking water wells.

Upon returning to the office, samples were placed in styrofoam coolers for shipment the following day to the State Laboratory of Hygiene (SLOH) in Madison. SLOH usually reported the analytical results within 4-5 weeks upon which these results were forwarded along with an explanatory letter to the well owners.

The three monitoring wells included in this study were installed in 1993 in the vicinity of an arsenic impacted private well. The sampling was performed by a private consultant according to appropriate WDNR procedures.

4 Results

A table of groundwater results can be found in Appendix B. Table 4.1 lists the 74 wells in the same general format as shown in Table 3.3. The table identifies the number of Drinking Water Standard (DWS) exceedances for arsenic at any one sampling event over the full ten-month sampling period. Wells sampled in the Town of Algoma are listed separately due to the higher number of DWS exceedances in this general area. It is consistent with previous studies that the Town of Algoma would have the highest percentage of DWS exceedances which in this case was about 24% (4 of 17).

Table 4.1: *Number of Drinking Water Standard (DWS) exceedances in all 74 wells and for wells in the Town of Algoma.*

	Type of well		Amount of casing into sandstone for new wells (feet)			
	Recon.	Replace.	<5	5-40	41-79	80+
Township of Algoma						
DWS exceeded	1	-	3	-	-	-
DWS not exceeded	4	1	5	1	1	1
All other selected townships						
DWS exceeded	1	1	1	-	-	-
DWS not exceeded	-	2	36	9	2	5
Total (74)	6	4	45	10	3	6

\- *No wells in category*

80+ *80 feet of casing into St. Peter Sandstone or drawing water from below this aquifer*

Based on the sampling results, almost 9.5% (7 of 74) of all the wells included in this study did exhibited water that exceeded the DWS on at least one occasion. This percentage is approximately three times higher than that seen in other arsenic studies in northeast Wisconsin. The reason for this variation is probably because <u>all</u> wells included in this study penetrated the St. Peter Sandstone (SS) aquifer where the majority of arsenic-tainted water is believed to be located. In previous studies, wells drawing water from above or below the SS were also included and this would tend to produce a lower percentage of wells exceeding the DWS.

In an effort to better evaluate the arsenic groundwater data for any seasonal trends, arsenic concentrations versus collection periods were plotted (see Figure 4.1). Please note that two additional wells with a history of arsenic exceedances were included during the last two sampling rounds. The highest arsenic level detected during this study was identified during the last sampling round in one of these two additional wells. Figure 4.1 does not appear to indicate any significant seasonal trends. The groundwater trends in this chapter should not be construed as based on an in depth statistical analysis but merely as an indicator of general trends and correlations.

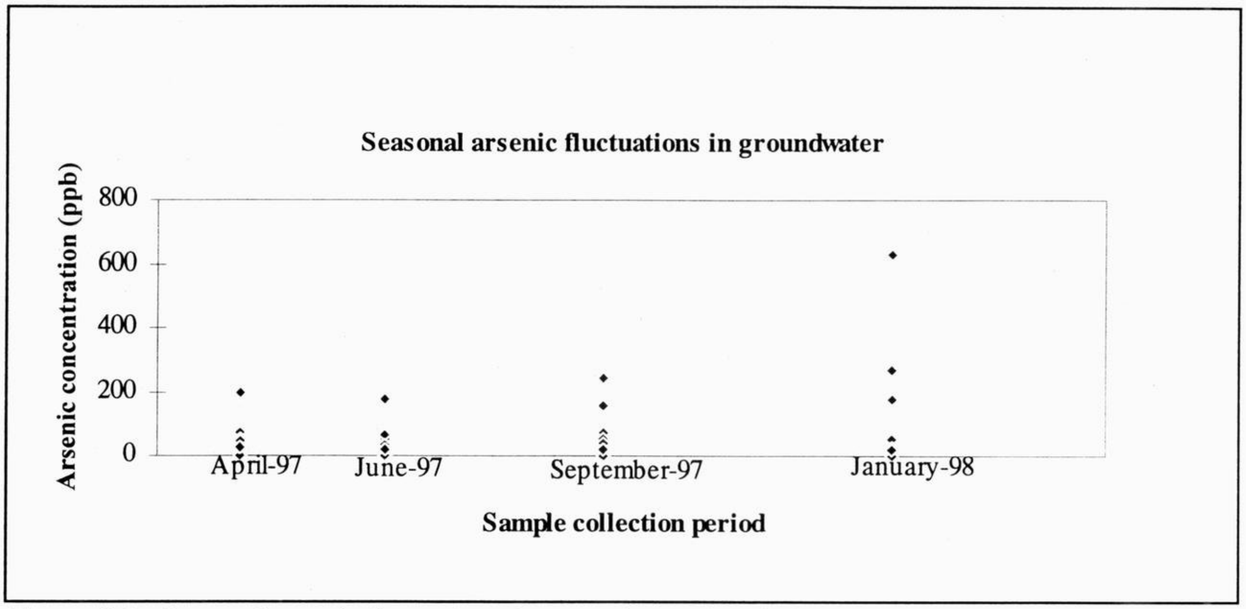

Figure 4.1: Seasonal arsenic fluctuations in groundwater for all drinking water wells included in study.

Figure 4.2 is similar to Figure 4.1 except that all arsenic data above 75 ppb is omitted (removal of outliers).

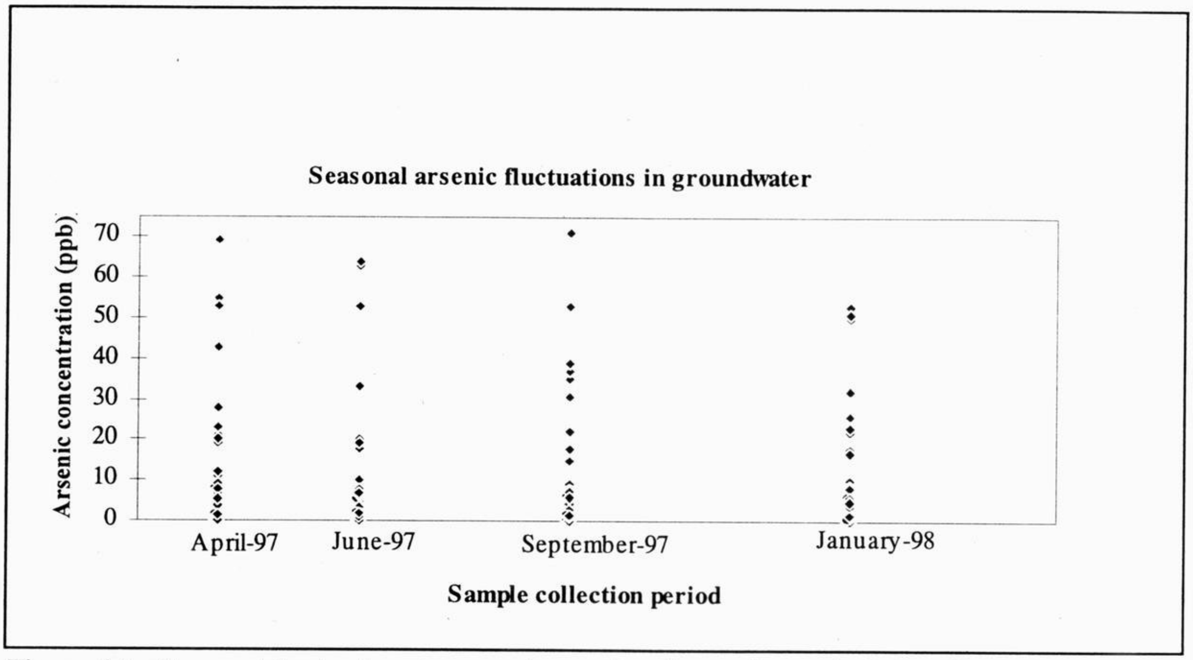

Figure 4.2: Seasonal fluctuations in groundwater for all arsenic results below 75 ppb.

Neither Figure 4.1 nor 4.2 appears to indicate any significant seasonal trends. This was also the initial conclusion drawn while reviewing the raw data only. As a whole, the arsenic levels in groundwater appeared to be fairly stable during the span of this study.

The data from each sampling event were evaluated using a least squares regression analyses. The regression line, slope equation, and the regression coefficient are displayed on graphs in Figures 4.3, 4.4, and 4.5.

In previous studies a direct correlation between high arsenic and high iron levels has been cited. According to Figure 4.3, there appears to be a correlation between high arsenic levels and high iron levels. This is reasonable and consistent with the general chemistry of pyrite oxidation which is the proposed chemical reaction releasing arsenic to the ground water.

The trendlines included in Figure 4.3 seems to indicate this correlation for all four sampling rounds. Please note that the trendline is based on a somewhat poor fit to the data as indicated by the relative low R^2 value (the closer the R^2 value is to 1, the better the trendline fits the data). The correlations seem to vary greatly for different sets of groundwater data for some unknown reason. Something to keep in mind is that each well is unique and one has to be careful when generalizing. For example, one of the wells sampled measured arsenic around 200 ppb in groundwater and iron at less than 1 ppm.

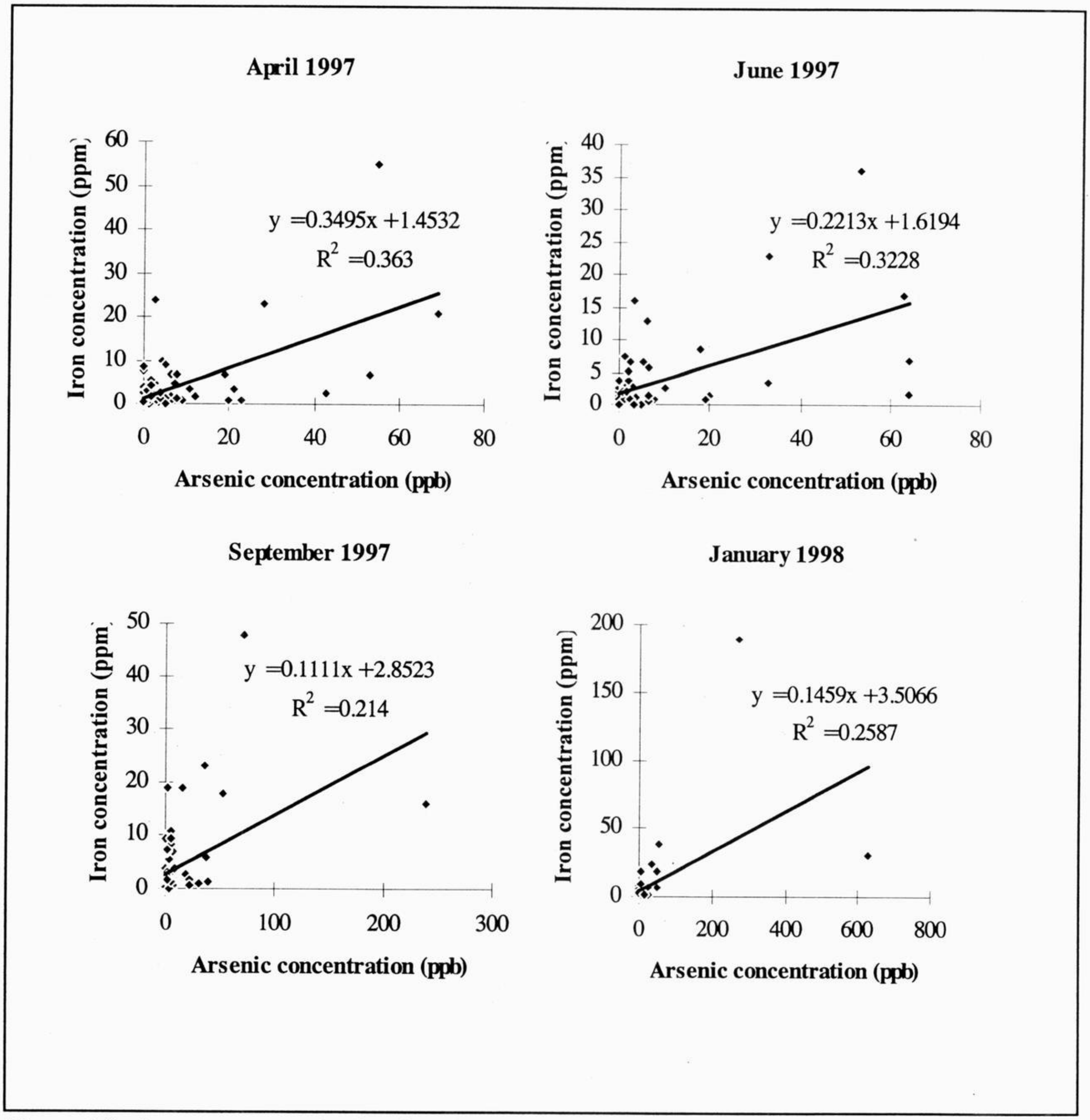

***Figure 4.3**: Iron versus arsenic plots for all the sampling rounds included in this study. All the sampling results are included except for data from one well that consistently identified high arsenic and extremely low iron levels.*

Another often cited relationship is the correlation between high arsenic and relatively low pH levels. In an effort to investigate this phenomenon further, the pH levels were plotted against the arsenic concentrations (see Figure 4.4). Again, a relatively poor correlation occurred as demonstrated by the low R^2 value. However, there appeared to be the same general trend for all sampling events indicating a correlation between high arsenic and low pH. That is, even with a low R^2 value, all four sets of samples show a downward trending pH with an increase in arsenic concentrations.

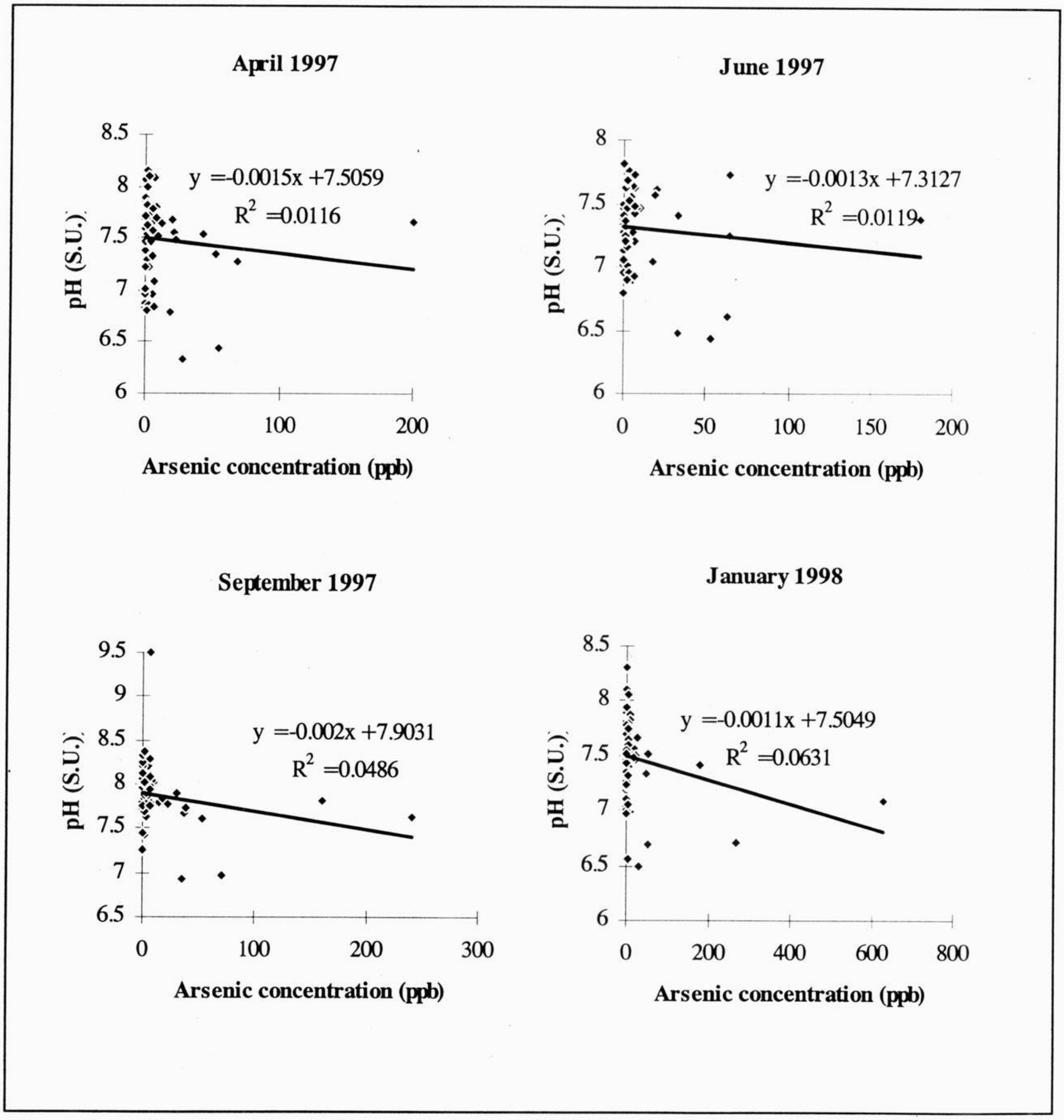

***Figure 4.4:** pH versus arsenic plots. All data included.*

Figure 4.5 depicts the relationship between arsenic concentrations in groundwater and conductivity. Once again, a relatively poor fit of the trendline to data points occurred, although the trendline does indicate a relationship between high arsenic and high conductivity. This is expected since the level of conductivity in water is determined by the amount of dissolved ions in a specific sample. Thus, these statistical analyses appear to support previous research results.

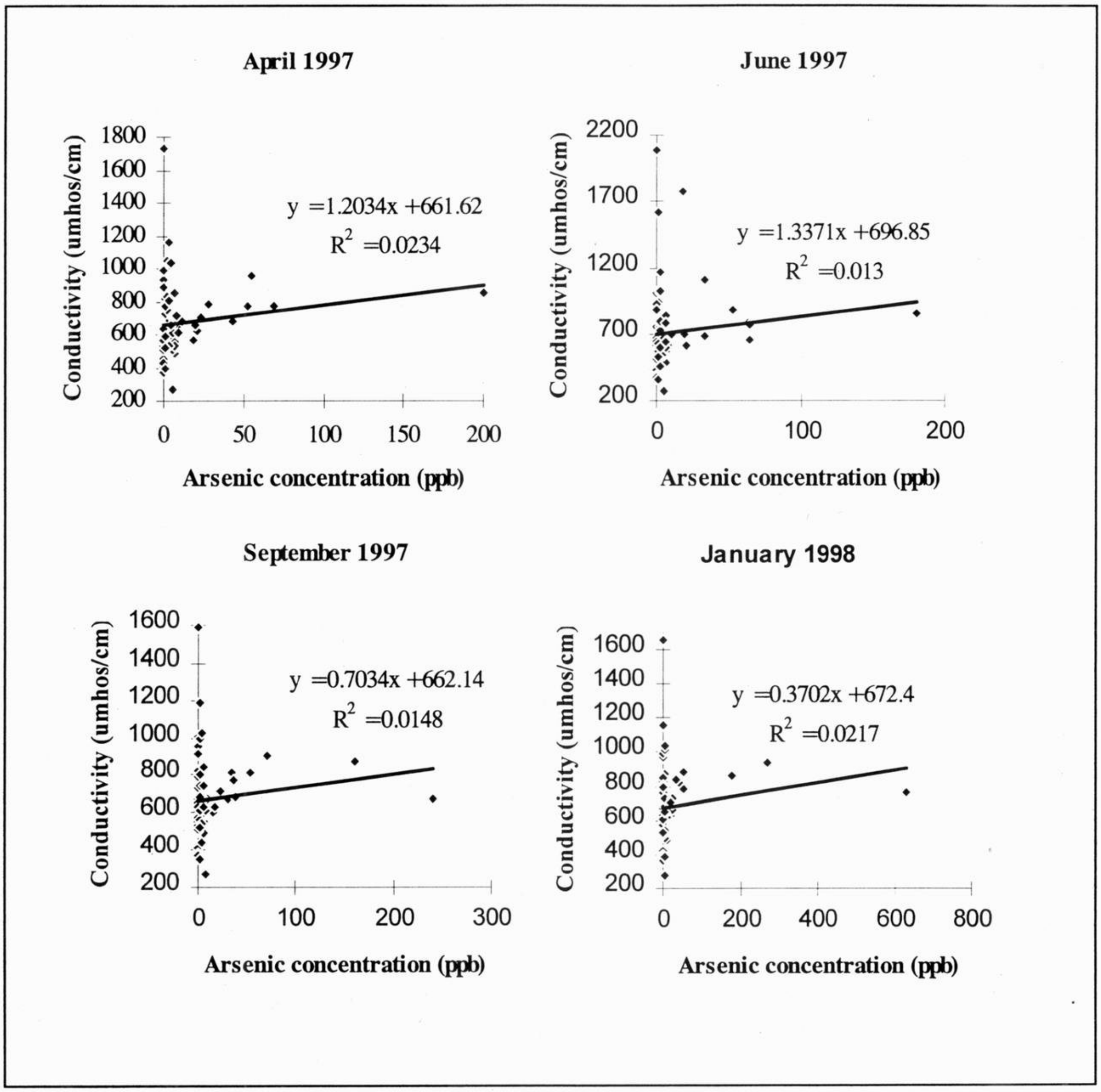

Figure 4.5: *Conductivity versus arsenic plots. All data included.*

Figure 4.6 presents the relationship between the amount of casing into the SS aquifer and the arsenic concentration in the water generated from the wells included in this study. Generally, it can be said that the highest levels of arsenic are found in wells with no casing extending into the sandstone aquifer (see data points on y axis). However, the wells with casing extending into the sandstone aquifer that still exhibit elevated arsenic levels are almost exclusively wells that have been either replaced or reconstructed. In these cases, it appears that the remedies did not alleviate the arsenic problem completely.

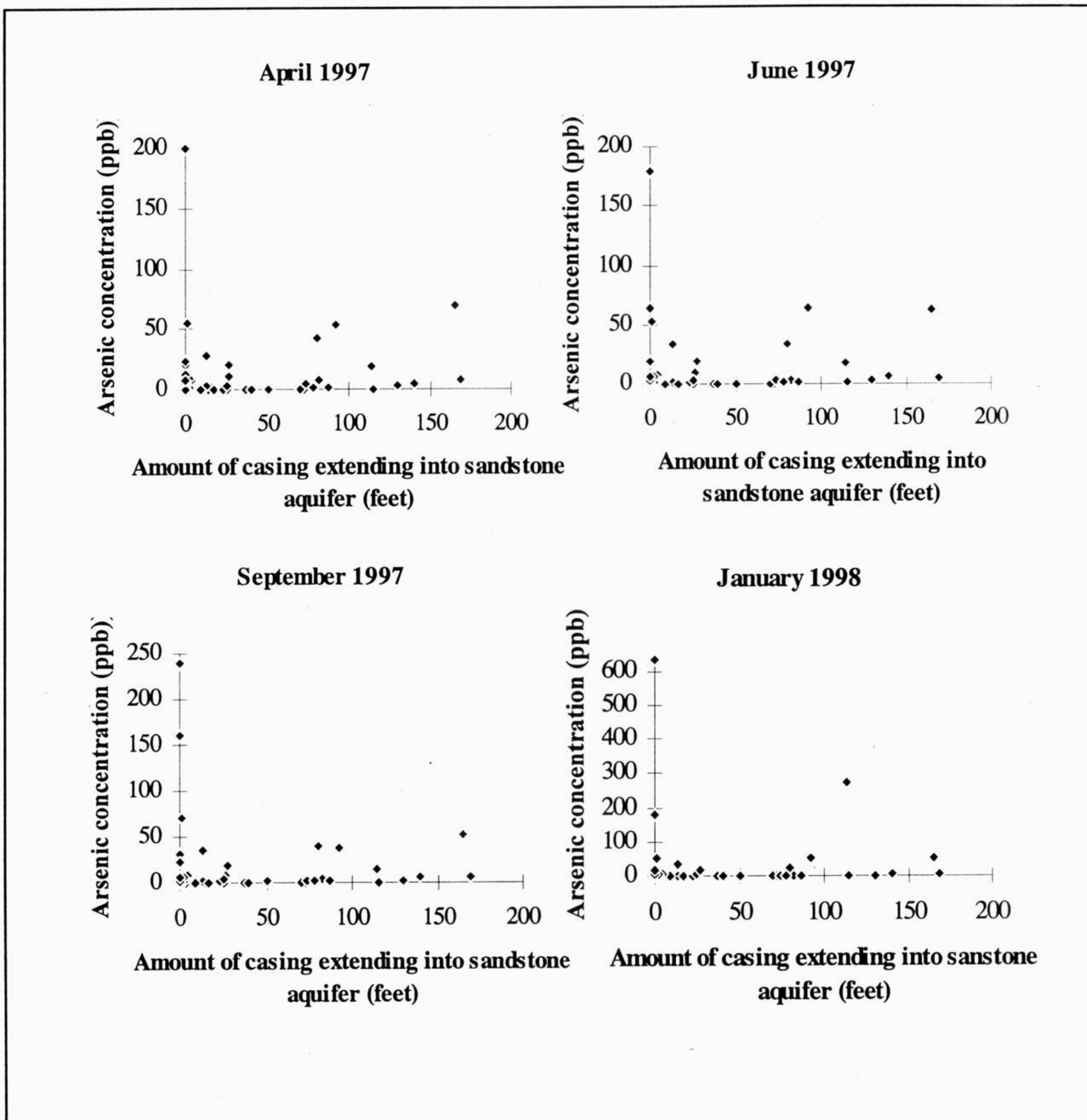

Figure 4.6: *Arsenic concentration versus casing depth into sandstone aquifer. All data included.*

Some of the elevated arsenic levels identified in Figure 4.6 from wells with a substantial amount of casing, are actually generated in wells that have undergone reconstruction or have been replaced. This is investigated further in Table 4.2.

***Table 4.2:** Highest arsenic levels identified in reconstructed and replaced wells during this study.*

Well type	Total number of wells	Highest arsenic level identified during study (ppb)			
		< 5	5-20	21-49	≥ 50
Reconstructed	6	2	1	1	2
Replaced	4	2	1	0	1

During the course of this study it was noted that the arsenic levels in two different drinking water wells exceeded the drinking water standard only once. Before and after these exceedances, the arsenic levels were well below the standard of 50 ppb. Homeowners living in the Arsenic Advisory Area (AAA) should keep in mind that seasonal variations of arsenic levels in drinking water are *possible*. Until more is understood about this phenomenon, it is advisable to not always collect a water sample during the same time of year but rather to space out the events to get a more representative picture of overall groundwater quality.

The groundwater samples collected from the three monitoring wells located in the Town of Oneida did not exhibit any increasing or decreasing trend for any of the parameters analyzed for (See Appendix B). With respect to the drinking water wells studied in this project, Figures 4.7 and 4.8 are included to give schematic representations of some interesting observations made.

Figure 4.7 identifies three drinking water wells located within approximately 200 yards of each other in the Town of Algoma. Well number 1 (originally a non-guidance well) was constructed in June 1995 without following the AAA guidance, with a minimal amount of casing, and open at the contact between the SS and the Galena-Platteville Dolomite (GP). It exhibited very high arsenic levels and was subsequently reconstructed in January 1996 by deepening the borehole and installing a liner with a packer (the packer is intended to seal the upper borehole and facilitate pumping of non-arsenic water from greater depths). Subsequent sampling revealed low to no detects of arsenic.

Well number 2 (also a non-guidance well) was constructed in a manner similar to well number 1, without following the AAA guidance, and is likely drawing water from near the contact between the SS and GP. (However, keep in mind that well number 2 was <u>not</u> reconstructed as well number 1 subsequently was). The exact depth of the pump is unknown; although it is assumed to be set at 30-35 feet below static water level. Arsenic levels as high as 600 ppb have been measured in this well.

Well number 3 was replaced (according to guidance) when the original shallow well exhibited high arsenic levels. In fact, the well driller went beyond the recommended 80 feet of casing and instead cased off the *entire* SS formation. Groundwater samples collected from this well had low level detects of arsenic. This is a good example of how the guidance recommendation of sealing off the upper portion of the SS is successful at preventing arsenic contamination of wells in this area.

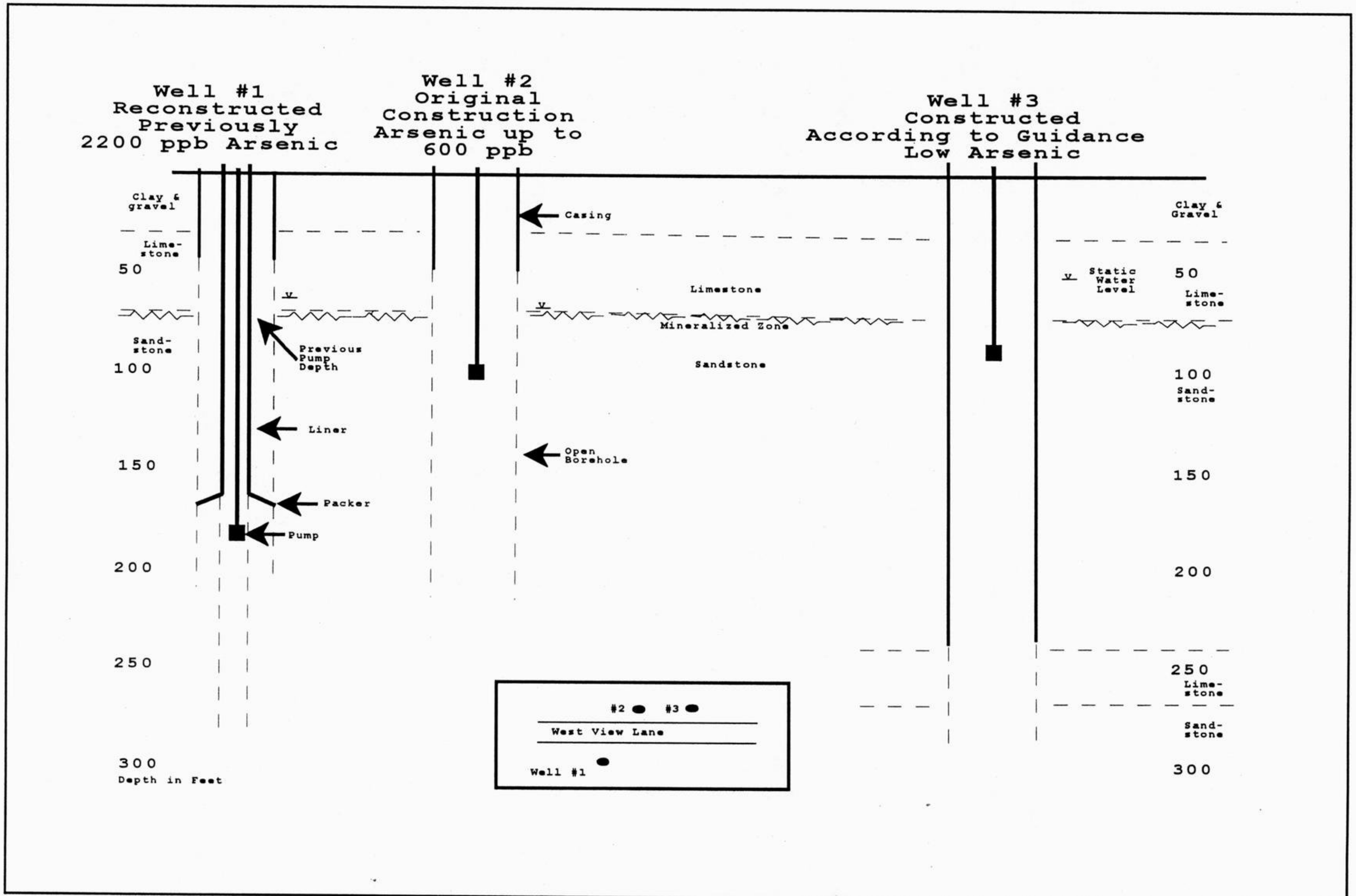

Figure 4.7: Select wells on West View Lane, Town of Algoma, Winnebago County (pump depths are assumed to be at 30-35 feet below static water level).

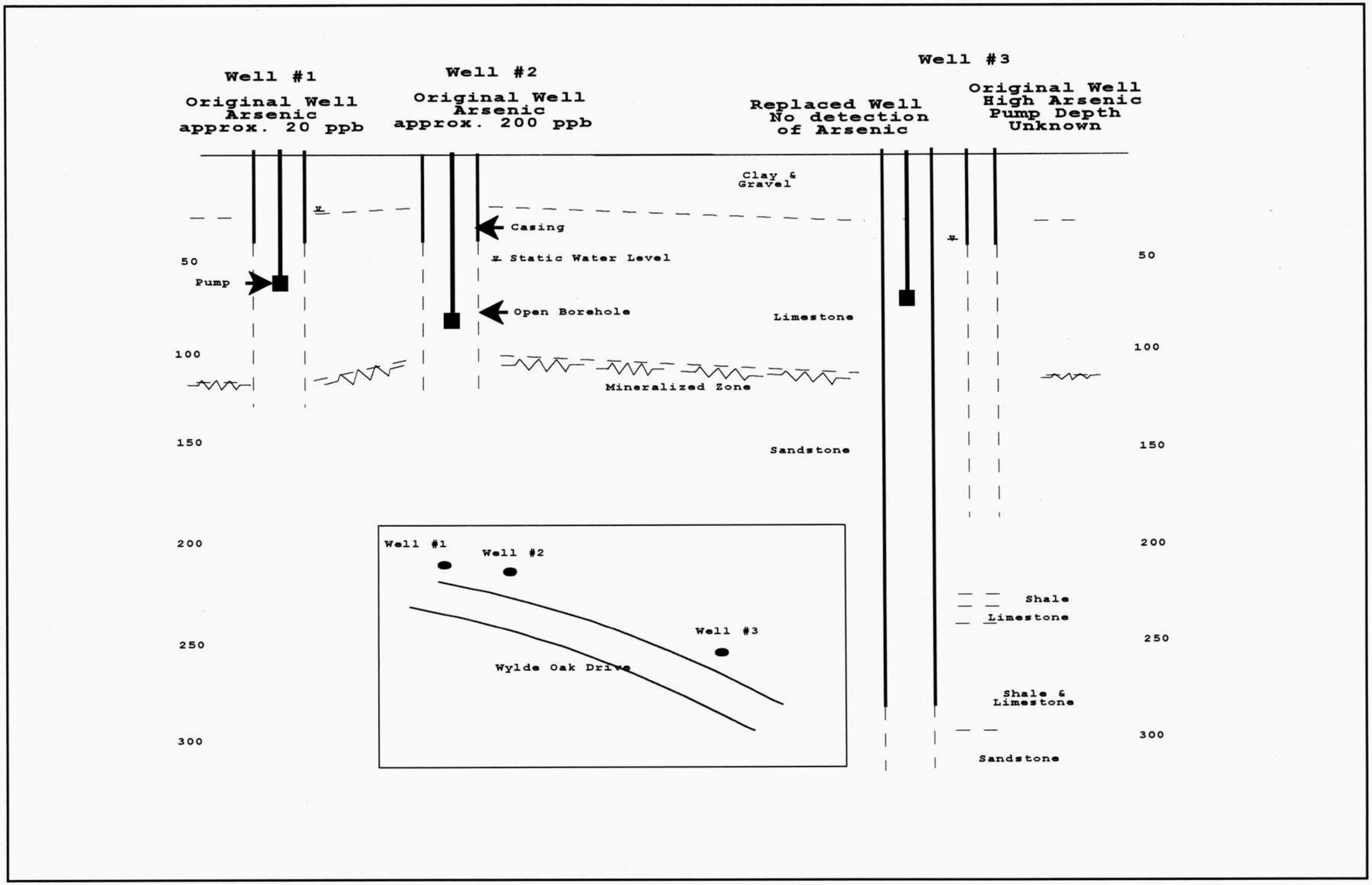

Figure 4.8: *Select wells on Wylde Oak Drive, Town of Algoma, Winnebago County (pump depths are assumed to be at 30-35 feet below static water level).*

Figure 4.8 also shows three drinking water wells located within approximately 200 yards of each other on another street in the Town of Algoma. Wells number 1 and 2 were constructed without following the recommended guidance, both with approximately 40 feet of casing (no casing extended through the top of the SS). They are both open to the contact between the SS and GP. It is postulated that the difference in arsenic concentrations may be due to the depth of the pump (please keep in mind that the exact depth of the pump placement is not known but contractors have reported that the pump is often placed 30-35 feet below static water level). The wells are in close proximity to each other, however, the static water level for well #1 (constructed July 1996) is reported at 29 feet below ground surface while the static water level for well #2 (constructed in January 1994) is reported at 50 feet below ground surface. It is possible that water for well #1 is being drawn from fractures in the GP dolomite (above the contact), whereas water for well #2 is withdrawn from the zone near the contact between the SS and GP. Well #1 exhibited arsenic in the range of 20 ppb whereas well #2 produced water containing arsenic at approximately 200 ppb. In other words, well #1 is drawing water from above the contact, perhaps a large fracture in the dolomite, whereas well #2 may be drawing water from near the contact and, more than likely, the mineralized zone. Perhaps the pump placement depth is in fact a significant factor in the concentrations of arsenic detected in drinking water wells in this area?

Well number 3 was originally constructed in January 1994 without following the guidance. Sample results revealed high arsenic concentrations. The well was subsequently abandoned and an entirely new well was constructed. The new well had ample casing length extending entirely through the SS and the groundwater results showed very low arsenic concentrations. This appears to illustrate that a replacement well constructed according to AAA recommendations is often effective in reducing arsenic concentrations in a well.

5 Conclusions

The objectives of this study were threefold: 1) to evaluate if the WDNR recommendations for well construction within the Arsenic Advisory Area (AAA) provide adequate protection, 2) to determine if arsenic concentrations increase over time, and 3) to examine if, when faced with a contaminated well, is it best to replace the well with a new one or to reconstruct the existing well with a liner.

To evaluate if the WDNR well construction recommendations within the AAA provide adequate protection against arsenic contamination, 19 wells that were constructed according to the guidance were compared with 45 wells constructed during the same time period but were <u>not</u> constructed with the additional casing recommendations. Survey results (see Table 3.3) found only approximately 13% of the wells constructed according to guidance, thus, it wasn't possible to locate the ratio of wells as originally proposed (25 wells each according to guidance and not according to guidance).

Water samples from wells constructed according to the guidance either did not have any detectable concentrations of arsenic or had few, very low level detections. None exceeded the drinking water standard for arsenic. On the other hand, wells constructed in the traditional manner, without the additional casing through the top of the St. Peter Sandstone (SS) formation, were significantly more likely to have detectable levels of arsenic in the water, and to exceed the drinking water standard.

The results from this study verify that the guidance (recommending casing through the top of the SS formation if the sandstone formation is penetrated) appears to provide adequate protection for wells constructed in the AAA. Moreover, when comparing the well construction of the various wells with their sample results, it was evident that as little as 40 feet of well casing sealing the top of the sandstone formation was as effective as the recommended 80 feet.

A second function of the research was to determine if arsenic concentrations increase over time. This was done because in part, the *Well Driller Guidance for Well Construction in Areas with Naturally Occurring Arsenic Water Quality Problems* recommends that upon completion of a newly constructed well, a water sample should be collected. WDNR staff have noted that the chemical reactions that initiate the arsenic contamination of wells appears to take a few years to manifest itself. A newly constructed well may test safe and yet detect steadily increasing concentrations of arsenic over the next few years. In cases such as these, a homeowner may unknowingly be consuming arsenic-contaminated water based on the initial water test. To study this, wells that were constructed during the years of 1994 and 1995 were sampled in this research project two and three years after construction. It is likely that some of these wells were sampled for arsenic upon construction and then not again until this study began.

Results of four sampling events collected from the 74 drinking water wells did not show any appreciable rise in arsenic concentrations over time. Three monitoring wells constructed in 1991, near a drinking water well with very high arsenic concentrations, were sampled at the same time as the 74 drinking water wells. The monitoring wells had not previously had any significant concentrations of arsenic detected in the past; it was thought that this was because the wells had not been in active use to replicate conditions conducive to the naturally occurring arsenic environment. Even with thorough purging of the wells during sampling events, the levels never increased and the phenomenon could not be proved.

However, the phenomenon of rising arsenic concentrations increasing over time is believed to occur because WDNR staff receive several calls per month relating to newly discovered arsenic detections in previously uncontaminated wells. A detailed review would need to be done of existing WDNR staff files, county health records, and previous research data to either prove or disprove the generally accepted notion that levels increase over time.

Lastly, the study examined data to determine if it was better to replace a contaminated well with a new one, or to reconstruct the existing well with a liner. The initial design of the research was to compare five reconstructed (lined) wells with fifteen fully replaced wells. However with the limited number of either types of wells, only six reconstructed wells and four replacement wells were located and sampled in this study. Of the four replacement wells, three were successful in eliminating or reducing the presence of arsenic, and of the six lined wells, three had very low or no detectable levels of arsenic. Nevertheless, there just weren't enough wells in the two categories to adequately determine if reconstruction, a less expensive option, is as effective as constructing a replacement well altogether.

6 Recommendations

Currently, the well construction guidance for the Arsenic Advisory Area (AAA) *recommends* that wells be constructed to withdraw water from the upper Galena-Platteville (GP) dolomite unit. However, should the borehole penetrate the St. Peter Sandstone (SS), the top 80 feet of the SS formation should be sealed by cement-grouting a protective well casing pipe through this upper portion. Based on results of this study, it is apparent that this recommendation is successful. The top of the SS unit should be cased off, however, it appears from examining well construction and sample results that casing the top 40 feet of the SS may be just as effective as casing off any greater amount. Therefore, the 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 SS if the SS is penetrated.

After reviewing the sample results from this study and consulting with the Winnebago County Health Department (which has an extensive arsenic water sampling program) it became evident that the AAA should be modified to *require* the special well construction procedures in two specific areas of concern. Exceedances were recorded within the AAA in only two townships, and at a significant regularity to warrant concern in only two townships: the Town of Osborn in Outagamie County and the Town of Algoma in Winnebago County. It is strongly recommended that the well driller guidance become a mandatory requirement and encompass only these two townships. Future research could potentially support the inclusion of more townships.

This brings to light the role of the local community governments and public health workers in dealing with the ever-changing understanding of this problem. For several years the Winnebago County Health Department has sought and received a grant to conduct extensive water testing of wells within the county. Arsenic is one of several parameters for which testing has been done. Local health departments are in the best position to keep abreast of the locations and concentrations of arsenic detects. It should be reinforced that they, as well as township boards and other interested parties, should communicate to the Department of Natural Resources any suggested changes to the advisory area requirements.

The sulfide mineral zone of the SS is typically a gray to black color. Drillers should be educated and made aware that when they encounter gray/black sandstone they are most likely drilling through the arsenic-bearing rock. The picture on the front cover of this report clearly shows the change in color of drilling fluids when the mineralized zone is encountered.

Since there is a likelihood of high iron in water withdrawn from the SS, homeowners often consider water treatment options to lower the iron concentrations in their water. Chlorination within the well, for instance using a pellet chlorinator, should not be used when the borehole is open to the top of the SS. This is because the chlorine acts as an oxidizer, and this very oxidation within the well may initiate the chemical reactions that releases the arsenic. Therefore, water treatment contractors and pump installers should be educated <u>not</u> to install or recommend an in-well chlorinator or oxidizer in these arsenic-prone areas.

Interestingly, it was postulated that the depth of the submersible pump within the well may also have an affect on the levels of arsenic in the well water. For instance, two wells were compared that were of similar construction and were located on adjacent lots. One had the pump placed near the arsenic bearing top of the SS, the other had the pump placed at a greater depth within the borehole. The well with the pump in closest contact to the top of the SS had high arsenic levels in the well water, whereas the well with the pump set further from the mineralized zone had low detectable levels of arsenic in water samples collected (See Figure 4.8, Well number 2). Further research is needed to determine if this is an anomaly or if indeed the placement of the pump influences where the water is drawn from and subsequently affects the levels of arsenic in the well water.

In summary, the recommendations based on this research are as follows:

1. Case off the *top 40 feet* of the SS when constructing a well into or through this unit.
2. Reduce the boundaries of the AAA to include only Osborn Township in Outagamie County and Algoma Township in Winnebago County.
3. Encourage local agencies such as county health departments, who may routinely collect information on arsenic results, to suggest to the WDNR when the AAA boundaries should be adjusted or when they are detecting new or significant information on the occurrence of arsenic in well water.
4. *Require*, rather than only recommend, construction of new wells within the AAA to follow special construction methods.
5. Alert well professionals that encountering black or gray sandstone while drilling is a warning sign that this likely is an arsenic bearing zone.
6. Discourage use of pellet chlorinators within the AAA when the open borehole extends into the SS, because chlorine is an oxidizer and may initiate the chemical reactions leading to arsenic in well water.
7. Determine through future research whether the position of the pump within the borehole of a non-guidance well has an affect on the concentrations of arsenic in wells within the AAA.

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Websites with Arsenic Related Information

http://wso.net/wei/dch/acic

http://www.dainichi-consul.co.jp/english/arsen.htm

http://cnn.com/EARTH/9803/19/arsenic/index.html

http://www.epa.gov/OGWDW/ars/arsenic.html

http://water-environment.org/acic

Appendix A

Guidance for the Arsenic Advisory Area (AAA)

February 1998

GUIDANCE

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, and 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 a 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.** Our experience tells us this will eliminate or reduce the bulk of the arsenic problems. There are no guarantees, regardless of well construction.

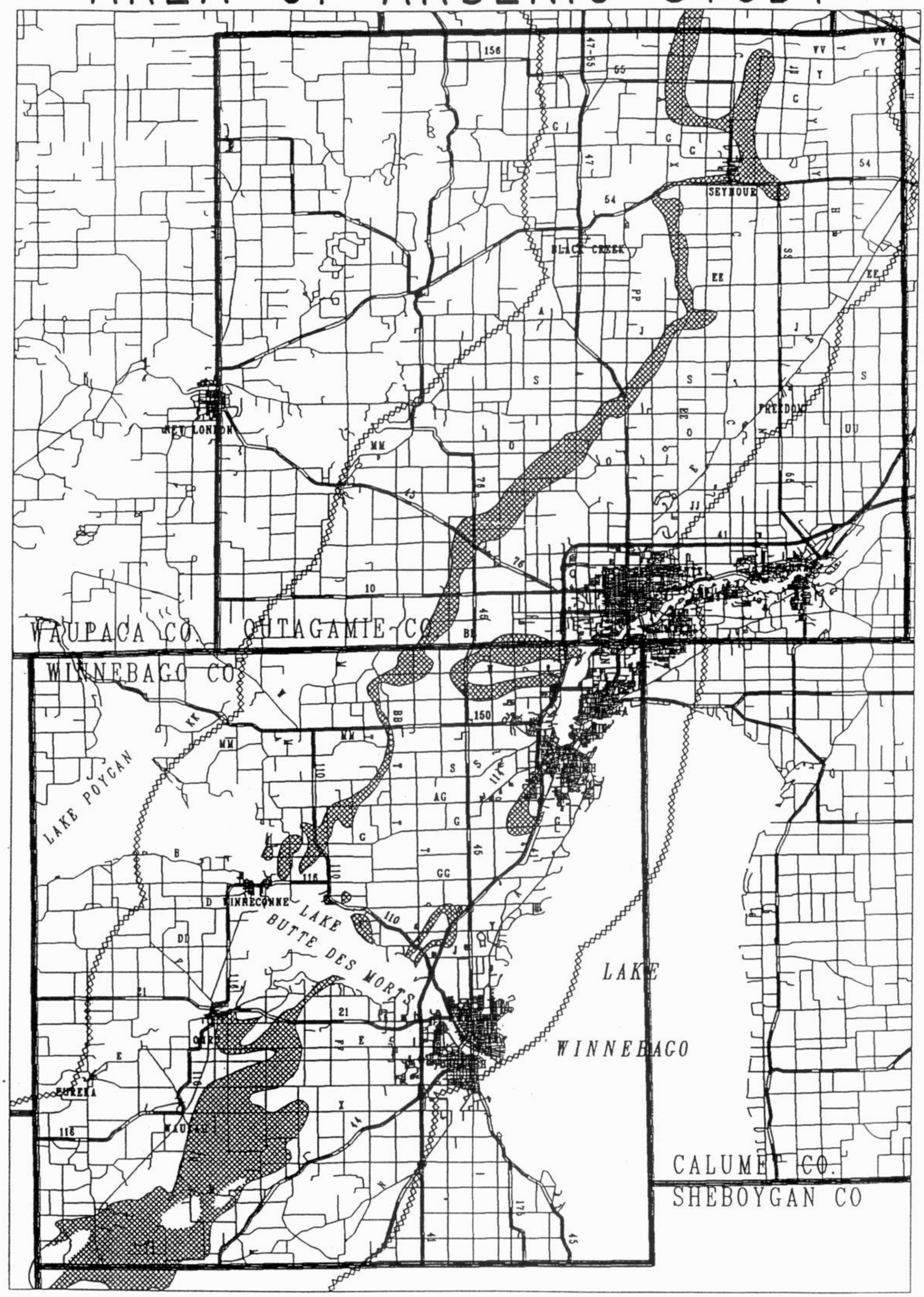
3. **Well drillers should contact Gary Paplham at the Lower Fox River Basin Office in Green Bay (920-448-5132) prior to construction of wells in the Townships of Hobart and Lawrence in western Brown County.** Mr. Paplham can provide you with information on the exact areas with known arsenic problems, and is also responsible for Outagamie County. Jerry Miller at our Oshkosh Service Center (920-424-7888), 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.

AREA of ARSENIC STUDY



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SCALE

0 MILES 5 10

Local Roads
State Highways
County Boundary
Five Mile Boundary Surrounding St. Peter Sandstone
St. Peter Sandstone

This map is not intended for regulatory use. This map is intended for informational purposes only.

The Wisconsin Department of Natural Resources is not responsible for the use or misuse of the information contained herein.

DEPT. OF NATURAL RESOURCES

More Questions and Answers about Arsenic
Wisconsin Division of Health

•WHAT ARE THE MAJOR SOURCES OF ARSENIC EXPOSURE?

People with average diets eat about 20 micrograms of inorganic arsenic a day. Fish products, especially shellfish, contain the greatest arsenic concentrations. A person with a high-seafood diet may consume greater amounts of arsenic than those without such diets. For the average person, water arsenic concentrations of 10 parts per billion (ppb) can double an person's inorganic arsenic intake if they drink about 2 quarts of water per day. Similarly, water containing arsenic at the standard of 50 ppb can increase a person's inorganic arsenic intake by five times.

Cigarette smoke also contains arsenic. An individual smoking two packs of cigarettes a day would inhale about 12 micrograms of arsenic a day.

•HOW CAN THE ARSENIC IN MY WATER ENTER MY BODY?

The vast majority of arsenic absorbed into the body is from drinking the water. Very little is absorbed through the skin. Therefore, showering and bathing in water containing arsenic presents little if any health hazard.

•WHAT SHOULD I DO IF I HAVE ARSENIC IN MY WATER?

Long.-term low-level arsenic exposure may cause an unusual pattern of skin changes. These changes may lead to skin cancer. This type of cancer is also caused by excessive sun exposure and is rarely fatal. Routine physical examinations, in which the skin is examined carefully, will usually detect skin problems associated with arsenic exposure. Eating or drinking greater amounts of arsenic may cause liver, kidney and digestive problems. These problems usually disappear after the person stops consuming the contaminated food or water.

•HOW CAN I GET MORE INFORMATION?

For more information, call:

Dennis Hibray, Regional Director
Wisconsin Division of Health
200 N. Jefferson St., Suite 211
Green Bay, WI 54301-5158
Tel. (920) 448-5223

OR

Mark Werner, Ph.D., Toxicologist
Wisconsin Division of Health
1400 E Washington Ave.
Madison. WI 53703
Tel. (608) 266-7480

Toxic Chemical Series

ARSENIC

This fact sheet is a reference for people who may be exposed to chemical contamination in the environment. It does not refer to occupational exposure or emergency situations.

Chemical reference number (CAS): 07440-3802

Also known as: Arsen, Arsenia

WHAT IS ARSENIC?

Arsenic is a naturally occurring element in the earth's crust, and is found in all living organisms. It is a silver-gray or tin-white, brittle, metallic substance. Arsenic is odorless and nearly tasteless.

Arsenic is used primarily in pesticides. It is also used in metal, glass and electronics manufacturing. Arsenic is important in the treatment of some human and animal diseases.

Household products such as ant poison and wood preservative contain arsenic. It is also found in cigarettes and cigarette smoke.

HOW ARE PEOPLE EXPOSED TO ARSENIC?

Arsenic may be absorbed when taken in by mouth, by breathing, or when skin or mucous membranes are exposed. Arsenic usually enters the body through the mouth, either in food or in water. It does not usually build up in the body.

For most people, food is the largest source of arsenic intake, with lower amounts from drinking water and air. The principal air release of arsenic in the U.S. is from coal-fuel power plants.

Levels of exposure that may lead to serious human health effects can occur in drinking water. Arsenic in drinking water can come from natural mineral deposits, pesticide use, or improper disposal of arsenic chemicals. Plants grown in arsenic-contaminated soils or sprayed with arsenic compounds may contain higher levels of arsenic than normal. Dolomite and bone meal used as nutritional supplements may also contain arsenic.

Since children are known to eat more soil than adults, and since they are more sensitive as a result of their small size and rapid development; contaminated soil may be of particular concern.

DO STANDARDS EXIST FOR REGULATING ARSENIC?

WATER

The Wisconsin Groundwater Enforcement Standard for private residential wells is 50 parts per billion (ppb). It is advisable to stop drinking water that contains more than that amount.

WHAT LEVELS OF EXPOSURE HAVE RESULTED IN HARMFUL HEALTH EFFECTS?

It is difficult to determine at what level arsenic causes specific health effects. The type and severity of health problems associated with exposure to arsenic are dependent on several factors:

* Previous exposures to chemicals;
* Amount of chemical exposure;
* Duration of the exposure;
* Route of exposure, i.e., whether the chemical exposure occurred by eating, drinking, skin contact or breathing;
* Age, sex, weight, ethnic background, and genetic factors;
* Personal habits such as cigarette smoking, medication use, or alcohol consumption;
* General health of the exposed individual;
* Individual reaction to chemical exposure.

The following health effects may occur immediately or shortly after exposure to low levels of arsenic;

* When taken by mouth (levels greater than 100 ppb in water) irritation of the digestive tract may occur. Symptoms may include nausea, diarrhea, loss of appetite and weakness.
* When exposure to arsenic dusts in air occurs, irritation of skin, eyes, or throat may result.

The following long-term effects can occur after exposure to arsenic:

* Cancer: Increased lung cancer rates occur in persons with high exposures to airborne arsenic in occupational settings. Arsenic in drinking water increases the risk of skin cancer.
* Reproductive Effects: It is uncertain whether low doses of arsenic cause reproductive problems or birth defects.
* Nerve damage: Numbness and tingling in arms and legs, muscle weakness may result.
* Organ Damage: Skin irritation that includes scaling and darkening is the primary effect from exposure to airborne arsenic. Serious effects on bone marrow, the liver and kidneys may occur.

Seek medical advice if you are experiencing any symptoms that you think may be related to chemical exposure.

IS THERE A MEDICAL TEST TO DETERMINE IF SOMEONE HAS BEEN EXPOSED TO ARSENIC?

Most arsenic is cleared from the blood within a few hours, so measurements of blood arsenic reflect only very recent exposures. Since most absorbed arsenic is quickly eliminated in urine, tests of urinary arsenic levels are useful as indicators of recent exposure. Urine levels of arsenic may be elevated, up to four hours, after eating some types of seafood. Arsenic tends to accumulate in hair and nails from external as well as internal sources. Such measurements may be a useful indicator of long-term arsenic exposure, but may not be definite evidence that a high dose has been absorbed.

This fact sheet summarizes information about this chemical and is not a comprehensive listing of potential effects. For more information contact the local Poison Control Center (the number is on the inside cover of phone books), your local public health agency, or write to the Division of Health, Environmental and Chronic Disease Section, Room 318, P.O. Box 309, Madison, WI 53701-0309.

Prepared by
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U.S. Agency for Toxic Substance and Disease Registry
(October 1990)

Appendix B

Groundwater data

COUNTY	TOWNSHIP	WELL TYPE	CASING (ft)	Arsenic (ppb)				Iron (ppm)				pH (S.U.)				CON. (umhos/cm)			
				04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98
OUTAGAMIE	SEYMOUR	NEW	0	6.6	6.8	6.6	7.6	1.3	0.86	0.91	0.93	7.08	7.21	8.08	6.99	483	486	488	486
OUTAGAMIE	OSBORN	NEW	40	0	0	0.9	1.1	2.4	3.8	2.7	2.1	6.84	7.12	7.96	7.03	532	673	577	586
OUTAGAMIE	OSBORN	NEW	13	28	33	35	32	23	23	23	24	6.34	6.48	6.94	6.49	779	1104	812	835
OUTAGAMIE	OSBORN	NEW	0	0	0	2.5	4	0.05	0.06	0.05	0.04	6.87	6.94	8.04	7.76	538	525	526	530
OUTAGAMIE	OSBORN	NEW	0	3.3	3.6	3.4	4.2	0.62	0.84	0.71	0.64	6.85	6.93	8.02	7.62	751	720	653	623
OUTAGAMIE	OSBORN	NEW	50	0	0	1.4	0.6	2.1	1.3	1.6	3.5	7.2	7.13	8.04	7.19	550	2080	546	560
OUTAGAMIE	OSBORN	NEW	1	55	53	71	53	55	36	48	39	6.43	6.44	6.98	6.69	958	878	906	887
OUTAGAMIE	ONEIDA	NEW	0	5.1	5	5.2	6.4	0.23	0.19	0.27	0.3	6.96	7.27	8.27	8.08	560	539	550	558
OUTAGAMIE	ONEIDA	NEW	0	0.7	0	0.8	0.8	0.68	0.94	1.2	1	6.81	7	7.74	7.75	781	765	825	835
OUTAGAMIE	ELLINGTON	NEW	14	0	0.8	0	0	2.5	1.2	3.4	2.5	8.07	7.63	8.18	7.92	515	520	517	525
OUTAGAMIE	ELLINGTON	NEW	2	5.8	6	5.2	3.5	0.97	1	1.5	3.2	7.66	7.46	8.2	7.84	505	572	500	502
OUTAGAMIE	ELLINGTON	NEW	0	0	1	0	0.6	0.01	0	0	0.02	7.38	7.15	7.76	7.48	936	944	958	976
OUTAGAMIE	ELLINGTON	NEW	0	0	0.6	0	0	0.11	0.06	0.09	0.06	7.86	7.17	8.02	7.48	765	750	734	768
OUTAGAMIE	ELLINGTON	NEW	1	6.7	5.8	6.4	6	1.5	0.57	0.36	0.3	8.08	7.51	8.29	7.82	550	536	495	540
OUTAGAMIE	CENTER	NEW	72	0	0	0	0	2	3	0.8	1.1	7.72	7.24	7.73	7.3	611	618	621	619
OUTAGAMIE	CENTER	NEW	2	0.8	1.4	0.8	1.2	3.3	3.4	4	3.5	8.15	7.31	8.06	7.7	663	654	658	668
OUTAGAMIE	CENTER	NEW	0	0	0	0	0.6	0	0	0	0	7.57	6.8	7.85	7.09	536	661	502	553
OUTAGAMIE	CENTER	NEW	0	0	0	0	0	0.06	0.05	0.14	0.05	7.9	7.02	7.87	7.26	450	429	415	416
OUTAGAMIE	CENTER	NEW	0	0	0	0	0	0.11	0	0	0	7.47	7.13	7.74	7.1	777	927	822	832
OUTAGAMIE	CENTER	NEW	1	6	5.7	7	6.1	0.63	0.33	0.26	0.19	7.56	6.9	9.5	6.56	265	266	266	275
OUTAGAMIE	FREEDOM	NEW	25	0	0	0	0	0.54	0.21	0.26	0.56	7.89	7.4	8.21	8.06	404	380	382	398
OUTAGAMIE	FREEDOM	NEW	70	0	0.7	0	0	0.41	0.35	0.92	0.37	7.59	7.36	8.24	8.31	432	374	377	387
OUTAGAMIE	FREEDOM	NEW	37	0	0	0	0	1.1	0.64	0.72	0.92	7.89	7.37	8.33	8.06	374	373	373	375
OUTAGAMIE	FREEDOM	NEW	0	2.5	2.7	2.2	0	4.7	0.73	1	0.16	8.1	7.21	7.98	7.31	572	553	564	554
OUTAGAMIE	FREEDOM	NEW	1	1.2	1.5	1.5	1.8	1.7	0.54	1.3	0.86	8	7.31	8.38	8.11	395	353	355	362

(shaded) : Exceedance of arsenic Drinking Water Standard (DWS = 50 ppb)

MW : Monitoring well

0 : No detection

Blank : No sample collected

COUNTY	TOWNSHIP	WELL TYPE	CASING (ft)	Arsenic (ppb)				Iron (ppm)				pH (S.U.)				CON. (umhos/cm)			
				04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98
OUTAGAMIE	FREEDOM	NEW	0	0.9	0	0	0	0.1	0.15	0.18	0.26	7.27	7.33	7.91	7.89	819	555	822	743
OUTAGAMIE	FREEDOM	NEW	0	0	0	0	0	0.34	0.23	0.19	0.19	7.68	6.95	8	7.94	598	568	550	562
OUTAGAMIE	GRAND CHUTE	NEW	0	0	0	0	0	0.33	0.26	0.29	0.37	7.52	7.28	7.8	7	508	515	513	518
OUTAGAMIE	GRAND CHUTE	NEW	0	0	0	0	0	0.03	0.02	0.04	0.03	6.96	7.47	7.44	7.44	985	1012	1004	993
OUTAGAMIE	GREENVILLE	NEW	16	1.9	1.7	1.6	1.6	1.2	0.76	0.88	0.89	7.3	7.18	7.77	7.11	832	796	794	810
OUTAGAMIE	GREENVILLE	NEW	3	2	2.1	0	2.5	2.3	2.5	9.5	1.9	7.84	7.41	8.13	7.39	665	665	649	678
OUTAGAMIE	SEYMOUR	REPLACED	82	7.3	2.6	3.8	2.6	4.7	6.5	5.5	5.3	6.84	7.01	7.71	8.06	532	449	439	387
OUTAGAMIE	CENTER	REPLACED	130	2.4	3.2	2.3	2.5	24	16	19	19	7.5	6.95	7.64	7.21	1048	1002	996	1012
OUTAGAMIE	GRAND CHUTE	REPLACED	165	69	63	53	50	21	17	18	19	7.28	6.61	7.6	7.34	766	776	818	812
OUTAGAMIE	OSBORN	RECONSTRUCTED	114	19	18	15	270	6.9	8.5	19	190	6.79	7.04	7.79	6.7	564	1776	598	938
WINNEBAGO	WINCHESTER	NEW	13	3.1	2.1	1.3	1.6	0.68	0.73	1	0.37	7.23	6.9	7.43	7.21	1158	1169	1191	1158
WINNEBAGO	WINCHESTER	NEW	9	0	0	0	1.1	1.5	2.1	0.54	1.6	7.81	7.37	7.93	7.81	590	590	631	590
WINNEBAGO	WINCHESTER	NEW	0	1.1	0.6	0.6	0	0.16	0.02	0.07	0.03	7.82	7.32	7.72	7.37	579	572	574	578
WINNEBAGO	WINNECONNE	NEW	17	0	0	0	0	7.6	1.9	2.4	1.3	7.54	7.5	7.81	7.54	662	662	672	669
WINNEBAGO	WINNECONNE	NEW	1	5	3	3.2	2.5	1.1	2.8	2.9	5.6	7.33	7.42	7.63	7.55	1029	1024	1030	1034
WINNEBAGO	WINNECONNE	NEW	0	0	0	0	0.9	2	2.7	2.2	1.7	7.59	7.49	7.81	7.47	643	636	650	654
WINNEBAGO	WINNECONNE	NEW	0	0.6	1.2	0	0	2.1	2	0.9	1.5	7.51	7.24	7.79	7.5	609	600	657	616
WINNEBAGO	WINNECONNE	NEW	0	0	0	0	0	3.9	3.6	4	4.4	7.64	7.81	7.95	7.76	533	535	535	539
WINNEBAGO	VINLAND	NEW	26	11	10	8.9	10	3.5	2.7	3.8	3.2	7.67	7.46	8.02	7.88	672	696	671	672
WINNEBAGO	VINLAND	NEW	4	8.2	7.8	7.6	8.5	0.76	0.85	0.81	0.8	7.81	7.46	8.05	7.82	607	609	617	625
WINNEBAGO	VINLAND	NEW	2	1	1.4	1.1	1.2	3.2	2.5	3.2	2.6	7.62	7.64	7.74	7.55	542	544	558	567
WINNEBAGO	UTICA	NEW	23	0	0.9	1.1	0	2.7	1.7	1.2	1.1	7.38	7.41	7.74	7.37	562	572	565	576
WINNEBAGO	UTICA	NEW	0	6.6	6.2	6.2	6	6.8	6.1	7	6.6	7.54	7.42	7.79	7.58	854	832	846	872
WINNEBAGO	UTICA	NEW	0	1.4	2	1.9	1.4	0.82	0.85	0.95	0.82	7.53	7.46	7.84	7.55	723	751	745	755
WINNEBAGO	UTICA	NEW	0	0	0	0.9	0	0.71	0.94	1.1	0.62	7.47	7.4	7.7	7.54	889	880	913	852

(shaded) : Exceedance of arsenic Drinking Water Standard (DWS = 50 ppb)

MW : Monitoring well

0 : No detection

Blank : No sample collected

COUNTY	TOWNSHIP	WELL TYPE	CASING (ft)	Arsenic (ppb)				Iron (ppm)				pH (S.U.)				CON. (umhos/cm)			
				04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98	04-97	06-97	09-97	01-98
WINNEBAGO	UTICA	NEW	0	4.4	6.2	5.5	4.7	9.8	13	11	6	7.57	7.63	7.81	7.45	604	599	600	599
WINNEBAGO	NEPEUSKUN	NEW	25	3.8	3.5	3.4	4.6	1.1	1.1	0.97	0.56	7.73	7.76	8	7.79	535	538	540	544
WINNEBAGO	NEPEUSKUN	NEW	40	0	0	0	0	0.03	0.01	0	0	7.02	7.06	7.44	6.97	633	633	628	670
WINNEBAGO	NEPEUSKUN	NEW	0	5.3	4.7	4.4	3.2	0.04	0.04	0	0.04	7.58	7.55	7.88	7.64	611	608	614	634
WINNEBAGO	OSHKOSH	NEW	0	1.9	2.2	1.8	2.2	5.5	3.7	6.9	1.1	7.69	7.16	7.88	7.06	744	728	741	766
WINNEBAGO	OSHKOSH	NEW	0	0	1.3	0.8	0	0.35	0.85	0.38	0.15	7.22	7.21	7.27	7.23	1732	1621	1586	1651
WINNEBAGO	OSHKOSH	NEW	0	**0.7**	**1**	**0**	**0**	2.8	2	1.9	2.1	7.65	7.36	7.75	7.35	775	789	799	812
WINNEBAGO	ALGOMA	NEW	27	21	20	18	18	3.3	1.4	2.9	1.3	7.56	7.61	7.84	7.56	623	606	629	627
WINNEBAGO	ALGOMA	NEW	74	4	2.6	2.5	1.9	2.6	0.83	2.6	2.9	7.46	7.7	7.9	7.43	808	800	800	797
WINNEBAGO	ALGOMA	NEW	169	7.9	5.3	5.7	6	6.7	6.5	8.5	7.3	7.7	7.64	7.98	7.53	663	670	673	687
WINNEBAGO	ALGOMA	NEW	2	9.2	6.3	7	8	0.68	0.54	0.59	0.67	7.52	7.48	7.93	7.52	607	603	609	619
WINNEBAGO	ALGOMA	NEW	0	20	64	31	22	0.97	1.8	1.2	1.1	7.68	7.72	7.9	7.47	662	660	671	662
WINNEBAGO	ALGOMA	NEW	0	200	180	160	180	0.91	0.77	0.78	0.83	7.66	7.38	7.81	7.41	848	853	879	862
WINNEBAGO	ALGOMA	NEW	0	12	3.2	2.7	3.7	1.6	0.07	0.08	0.07	7.65	7.52	8.03	7.59	684	610	681	684
WINNEBAGO	ALGOMA	NEW	0	7.8	6.5	5.7	5.7	1.3	1.5	1.5	1.4	7.8	6.93	7.76	7.31	719	784	747	724
WINNEBAGO	ALGOMA	NEW	0			22	23			1.6	1.6			7.76	7.49			710	734
WINNEBAGO	ALGOMA	NEW	0			240	630			16	30			7.63	7.08			672	766
WINNEBAGO	ALGOMA	REPLACED	115	0	1.2	0.9	0	8.3	7.4	7.2	7.6	7.72	7.62	7.99	7.54	630	624	633	632
WINNEBAGO	ALGOMA	RECONSTRUCTED	78	1.6	2.1	1.3	0.7	4.3	5.2	7.5	5.5	7.63	7.67	8.03	7.78	594	594	612	612
WINNEBAGO	ALGOMA	RECONSTRUCTED	92	53	64	37	51	6.8	7	5.8	6.2	7.35	7.25	7.67	7.51	766	766	772	790
WINNEBAGO	ALGOMA	RECONSTRUCTED	140	5.1	6.6	5.8	4.9	8.8	5.7	9.6	9.9	7.79	7.72	8.09	7.74	662	641	636	653
WINNEBAGO	ALGOMA	RECONSTRUCTED	80	43	33	39	26	2.5	3.5	1.4	6	7.54	7.4	7.73	7.66	685	676	685	692
WINNEBAGO	ALGOMA	RECONSTRUCTED	87	1.6	1.8	1.6	1.3	1.8	2	1.6	2.6	7.63	7.68	8.03	7.51	524	522	525	532
WINNEBAGO	ALGOMA	DEEPENED	0	23	19	22	17	0.83	0.77	0.79	0.78	7.48	7.56	7.77	7.48	704	702	713	706
OUTAGAMIE	ONEIDA	MW 1d		0	1.2	0	0.7	0.26	0.27	0.2	0.25	7.47	7.66	7.85	7.89	443	458	449	433
OUTAGAMIE	ONEIDA	MW 2s		1.7	2.6	0	1.2	0.01	0.09	0.65	0	7.21	7.28	7.62	7.64	843	806	711	728
OUTAGAMIE	ONEIDA	MW 3d		0	0.7	1.7	0	0.71	0.88	0	0.45	7.47	7.49	7.93	8	507	487	371	366

(shaded) : Exceedance of arsenic Drinking Water Standard (DWS = 50 ppb)

MW : Monitoring well

0 : No detection

Blank : No sample collected

A STUDY OF WELL CONSTRUCTION FOR ARSENIC CONTAMINATION IN NORTHEAST WISCONSIN

Annette E. Weissbach, M.S., Elizabeth M. Heinen, B.S., Keld B. Lauridsen, B.S.
Wisconsin Department of Natural Resources

Arsenic has been detected in approximately one third of the private drinking water wells in the Fox River valley of Northeast Wisconsin. Concentrations detected are some of the highest found naturally occurring in the world. Research has indicated that presently 3.5% of the wells in Outagamie and Winnebago counties exceed the current drinking water standard of 50 ppb.
Department of Natural Resources study results indicate the geochemical phenomenon causing the elevated levels of arsenic in groundwater of this region is associated with oxidation of a sulfide-mineralized zone located at the top of the deep sandstone aquifer system. A regional decline in water levels may have exposed this sulfide rich zone to oxidation from air within the open boreholes of water wells extending through this zone. This oxidation process can initiate a chemical reaction similar to acid mine drainage.
Recommendations have been developed for constructing wells within a delineated advisory area. This guidance recommends constructing wells with well casing pipe to extend through the sulfide rich zone. This study compared arsenic concentrations of wells constructed according to the guidance, with wells constructed to traditional construction standards. Additionally, this study examined data to determine if it was better to replace a contaminated well with a new one, or to reconstruct the existing well with a liner.
The results of this study indicate that the guidance gives adequate protection for wells constructed in the arsenic advisory area and that liners are successful at reducing arsenic concentrations, although not as successful eliminating arsenic contamination.

Geology

Quarternary Deposits – Predominantly fine grained tills and lacustrine silts and clays. Minor amounts of sand and gravel deposits are present throughout the area.

Sinnipee Group – Dolomite with a thin shale formation in the middle. The Galena- Platteville formations are massive and regionally acts as an aquitard , yet are good for domestic supply where weathered and fractured.

Ancell Group – St. Peter formation is a fine to medium grained sandstone with a thin silty sandstone formation on top and shale at the base. Thickness is variable in the area.

Prairie du Chien Group – Dolomite with varying amounts of oolitic chert. Thin or absent where the St. Peter is very thick.

Jordan Formation – Fine to medium grained sandstone.

Tunnel City Group - Fine to medium grained sandstone, silty sandstone and glauconitic dolomite.

Elk Mound Group – Very fine to fine grained sandstone and medium to course grained sandstone.

Precambrian – Granitic rocks, undifferentiated.

1 The original well on this property was constructed in 1978. It was 6" hole with casing to 44 feet and a total depth of 123 feet. In 1994 the well was sampled and had an arsenic level of 987 ppb. A new well was constructed to the recommended specifications. A 9" hole was drilled to 151 feet. Six-inch casing was installed to 152 feet. The total depth of the new well was 180 feet. In 1999 declining water quality lead to further investigation. Arsenic levels had again risen to the 1000 ppb level. It is suspected that problems with caving sandstone during the grouting process may have allowed the aggressive water to corrode the casing and contaminate the well. This same problem has been documented at a nearby well. A new 303-foot well with 250 feet of casing has been constructed on the property and has been fine so far.

2 This well was constructed in 1977, with 6" casing to 44' and a total depth of 123'. The contact between the Galena-Platteville dolomite and the St. Peter Sandstone was reported at 75'. In 1978 a packer was installed at 87' to reduce high iron. In 1990 the homeowners reported the water from this well to be an irritant to their skin, have a metallic taste and were deteriorating the plumbing fixtures. The DNR was contacted in 1991 and found that the water had a pH of 2.5

Sample results from 1992 were:

pH = 2.05
As = 4300+ ppb
Cr = 84 ppb
Cd = 220 ppb
Ni = 11000 ppb
Al = 15000 ppb
Co = 5500 ppb
Pb = 400 ppb

A new well was installed in 1993 as a shallow dolomite well with a total depth of 40'. The well continues to produce treatable potable water.

Sample results from that well in 1995 were:

pH = 7.08
As = 5 ppb
Ni = 8 ppb
Pb = ND

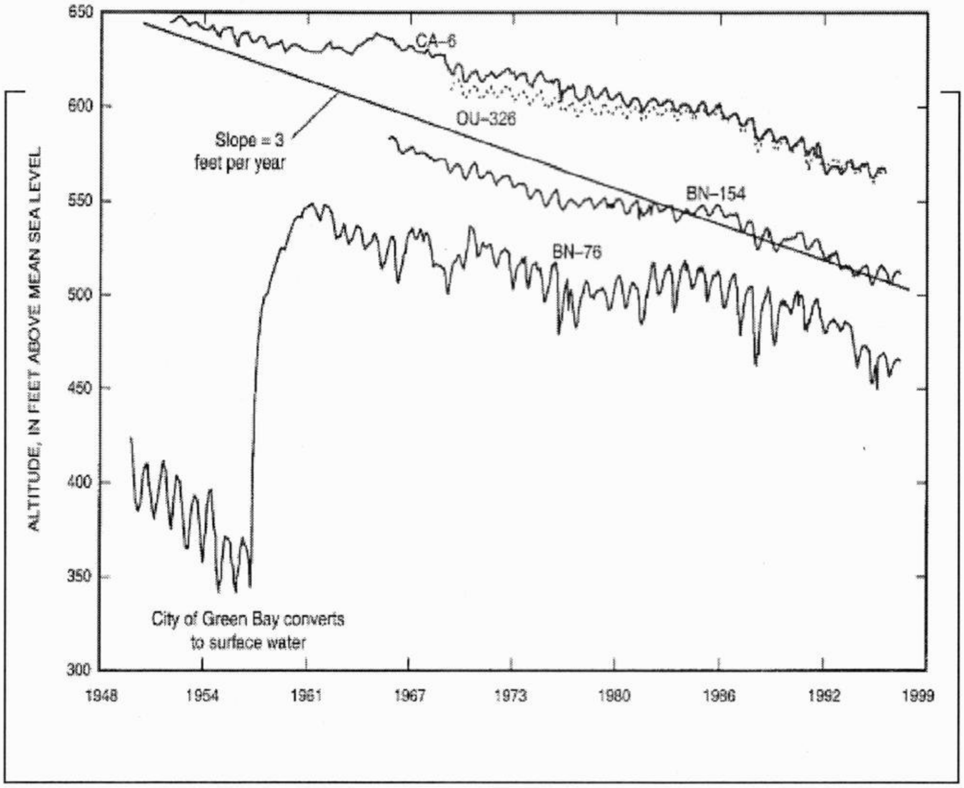
3 This well was constructed 1/92 to a total depth of 155' with casing set to 45'. The static water level was 70', which dropped to 94' while pumping. Normal pumping caused the water level to fluctuate across the contact of the Galena-Platteville dolomite and St Peter sandstone, the most concentrated zone of sulfide mineralization.

10/19/93 sample results

pH= 6.4
As = 12,000 ppb
11/17/93
As = 15,000 ppb

This well and a neighboring well were reconstructed by drilling deeper, into Cambrian sandstone and grouting in a 4" liner to 290'. Since then all arsenic results have been <5 ppb in one well and range from 1.2 to 6.6 in the other well. Another well right next door was drilled out to 243 feet and a 4" liner was grouted to 153'. Arsenic concentrations in the reconstructed well dropped to 18 ppb, but have been rising and are now in the 200 ppb range.

4 Oxidation of the sulfide minerals is being enhanced due to a large cone of depression caused by Municipal and Industrial pumping in the Green Bay area. As can be seen on this hydrograph, after an



initial rebound in 1957 when Green Bay switched to surface water for a municipal supply, the water levels have been declining at a rate of about 3 feet per year.

Land-use activities and development of high density housing (sub-divisions) have locally reduced infiltration along with higher water demands have also contributed to declining water levels. As can be seen on the attached well construction reports, two wells were replaced in 1995 for lack of water. The wells developed a problem with arsenic, with reported levels over 900 ppb. The construction reports for the new wells on the same properties indicate static water levels are 30 to 40 feet lower in 1998 than in 1995.

Mailing Address 269 ORLANDO RD
City DE PERE | State WI | Zip Code 54115
County of Well Location BROWN | Co. Well Permit No. | Well Completion Date September 1, 1995
5 Well Constructor (Business Name) VAN DE YACHT BILL WTR | License # 4462 | 2. Dates 09/08/95 Rc'd
4 Address 3671 MONROE RD
City DE PERE | State WI | Zip Code 54115 | Create 02/09/96 Last
P M=Munic. O=OTM N=NonCom P=Priv Z=Other X=Non-Pot. A=Anode L-Loop H=Drillhole

1. Well Location T T=Town C=City V=Village Fire #(If avail.)
of HOBART
Grid or Street Address or Road Name and Number
Subdivision Name | Lot # | Block #
Gov't Lot # ____ or NE 1/4 of NW 1/4 of
Section 27, T 23 N; R 19 E
3. Well Type 2 1 = New 2 = Replacement 3 = Reconstruction
of previous unique well # ____ constructed in 19 0
Reason for new, replaced or reconstructed well?
DRY WELL
1 1 = Drilled 2 = Driven Point 3 = Jetted 4 = Other

4. Well serves 1 # of homes and or (Ex: barn, restaurant, church, school, industry, etc.)
High Capacity: FM Well? N Property? N

5. Well located on highest point of property, consistent with the general layout and surroundings? Y
Well located in floodplain? N
Distance in Feet From Well To Nearest:

1. Landfill	9. Downspout/Yard Hydrant	17. Wastewater Sump
2. Building Overhang	10. Privy	18. Paved Animal Barn Pen
78 3. Septic or Holding Tank (circle one)	11. Foundation Drain to Clearwater	19. Animal Yard or Shelter
92 4. Sewage Absorption Unit	12. Foundation Drain to Sewer	20. Silo - Type
5. Nonconforming Pit	13. Building Drain 1 = Cast Iron or Plastic 2 = Other	21. Barn Gutter
6. Buried Home Heating Oil Tank	14. Building Sewer 1=Gravity 2=Pressure 1 = Cast Iron or Plastic 2 = Other	22. Manure Pipe 1=Gravity 2=Pressure 1 = Cast Iron or Plastic 2 = Other
7. Buried Petroleum Tank	15. Collector or Street Sewer	23. Other Manure Storage Other NR 112 Waste Source
8. Shoreline/Swimming Pool	16. Clearwater Sump	24.

6. Drillhole Dimensions

Dia. (in.)	From (ft.)	To (ft.)
9.0	surface	82.0
6.0	82.0	223.0

Method of constructing upper enlarged drillhole only.
X 1. Rotary - Mud Circulation
2. Rotary - Air
3. Rotary - Foam
4. Reverse Rotary
5. Cable-tool Bit ____ in. dia.
6. Temp. Outer Casing ____ in. dia. Removed?
7. Other

9. Geology

DNR USE ONLY	Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
C	CLAY	Surface	15.0
G	GRAVEL	15.0	20.0
L	LIME	20.0	100.0
N	SANDSTONE	180.0	223.0

7. Casing, Liner, Screen

Dia. (in.)	Material, Weight, Specification Manufacturer & Method of Assembly	From (ft.)	To (ft.)
6.0	NEW 6.1 ST PL END WELDED 1897 280 A53 SAWMILL	surface	83.0
Dia. (in.)	screen type, material & slot size	From	To

8. Grout or Other Sealing Material

10. Static Water Level 90.0 ft. B ground A=Above B=Below
11. Pump Test Pumping Level 120.0 ft below ground surface Pumping at 30.0 GPM 1.00 hrs
12. Well Is: 12 in. A Grade A=Above B=Below
Developed? Y
Disinfected? Y
Capped?
Depth (feet)

Mailing Address 269 ORLANDO DR

City DE PERE | State WI | Zip Code 54115

County of Well Location BROWN | Co. Well Permit No. | Well Completion Date September 23, 1998

5 Well Constructor (Business Name) VAN DE YACHT BILL WTR | License # 4462 | 2. Dates 10/07/98 Rc'd

4 Address 3671 MONROE RD

City DE PERE | State WI | Zip Code 54115 | Create 11/02/98 Last

P M=Munic. O=OTM N=NonCom P=Priv Z=Other X=Non-Pot. A=Anode L-Loop H=Drillhole

4. Well serves 1 # of homes and or HOMES (Ex: barn, restaurant, church, school, industry, etc.) | High Capacity: FM Well? N Property? N

1. Well Location T T=Town C=City V=Village | Fire # (if avail.)

of HOGAR

Grid or Street Address or Road Name and Number 269 ORLANDO DR

Subdivision Name | Lot # | Block #

Gov't Lot # ____ or NW 1/4 of NE 1/4 of Section 27 , T 23 N; R 19 E

3. Well Type 2 1 = New 2 = Replacement 3 = Reconstruction of previous unique well # ____ constructed in 19 0

Reason for new, replaced or reconstructed well? HIGH ARSENIC

1 1 = Drilled 2 = Driven Point 3 = Jetted 4 = Other

5. Well located on highest point of property, consistent with the general layout and surroundings? Y

Well located in floodplain? N

Distance in Feet From Well To Nearest:

1. Landfill
2. Building Overhang
78 3. Septic or Holding Tank (circle one)
92 4. Sewage Absorption Unit
5. Nonconforming Pit
6. Buried Home Heating Oil Tank
7. Buried Petroleum Tank
8. Shoreline/Swimming Pool
9. Downspout/Yard Hydrant
10. Privy
20 11. Foundation Drain to Clearwater
12. Foundation Drain to Sewer
13. Building Drain 1 = Cast Iron or Plastic 2 = Other
14. Building Sewer 1=Gravity 2=Pressure 1 = Cast Iron or Plastic 2 = Other
15. Collector or Street Sewer
16. Clearwater Sump
17. Wastewater Sump
18. Paved Animal Barn Pen
19. Animal Yard or Shelter
20. Silo - Type
21. Barn Gutter
22. Manure Pipe 1=Gravity 2=Pressure 1 = Cast Iron or Plastic 2 = Other
23. Other Manure Storage Other NR 112 Waste Source
24.

6. Drillhole Dimensions

Dia. (in.)	From (ft.)	To (ft.)
9.0	surface	239.0
6.0	239.0	261.0

Method of constructing upper enlarged drillhole only.

X 1. Rotary - Mud Circulation
2. Rotary - Air
3. Rotary - Foam
4. Reverse Rotary
5. Cable-tool Bit ____ in. dia.
6. Temp. Outer Casing ____ in. dia. Removed?
7. Other

9. Geology

DNR USE ONLY	Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
C	CLAY	Surface	15.0
G	GRAVEL	15.0	20.0
L	LIME	20.0	140.0
N	SANDSTONE	140.0	261.0

7. Casing, Liner, Screen

Dia. (in.)	Material, Weight, Specification, Manufacturer & Method of Assembly	From (ft.)	To (ft.)
6.0	NEW BL STL PL END WELDED 18.97 280 a53 SAWHILL	surface	240.0

Dia. (in.) | screen type, material & slot size | From | To

8. Grout or Other Sealing Material

10. Static Water Level 130.0 ft. B ground A=Above B=Below

11. Pump Test Pumping Level 160.0 ft. below ground surface Pumping at 40.0 GPM 1.00 hrs

12. Well Is: 12 in. A Grade A=Above B=Below Developed? Y Disinfected? Y Capped? Y Depth (feet)

SEYMOUR | State WI | Zip Code 54165

County of Well Location OUTAGAMIE | Co. Well Permit No. | Well Completion Date August 24, 1988

Well Constructor (Business Name) SCHMIDTS WATER SERVICE | License # 6 | 2. Dates 09/19/88 Rc'd

Address RT 3 BOX 27

City BLACK CREEK | State WI | Zip Code 54106 | Create 10/10/89 Last FM

M=Munic. O=OTM N=NonCom P=Priv Z=Other X=Non-Pot. A=Anode L-Loop H=Drillhole

serves 1 # of homes and or (barn, restaurant, church, school, industry, etc.) | High Capacity: Well? N Property? N

T 1=Town C=City V=Village | Fire # (if avail.)

of OSBORN

Grid or Street Address or Road Name and Number FRENCH ROAD

Subdivision Name | Lot # | Block #

Gov't Lot # ____ or SW 1/4 of NW 1/4 of Section 5 , T 23 N; R 18 E (E/W)

3. Well Type 2 1 = New 2 = Replacement 3 = Reconstruction of previous unique well # ____ constructed in 19 0

Reason for new, replaced or reconstructed well? OLD WELL CONTAMINATED

1 1 = Drilled 2 = Driven Point 3 = Jetted 4 = Other

located on highest point of property, consistent with the general layout and surroundings? Y

located in floodplain? N

in Feet From Well To Nearest:

1. Landfill
2. Building Overhang
3. Septic or Holding Tank (circle one)
4. Sewage Absorption Unit
5. Nonconforming Pit
6. Buried Home Heating Oil Tank
7. Buried Petroleum Tank
8. Shoreline/Swimming Pool
9. Downspout/Yard Hydrant
10. Privy
11. Foundation Drain to Clearwater
12. Foundation Drain to Sewer
13. Building Drain 1 = Cast Iron or Plastic 2 = Other
14 14. Building Sewer 1 1=Gravity 2=Pressure 1 1 = Cast Iron or Plastic 2 = Other
15. Collector or Street Sewer
16. Clearwater Sump
17. Wastewater Sump
18. Paved Animal Barn Pen
19. Animal Yard or Shelter
20. Silo - Type
21. Barn Gutter
22. Manure Pipe 1=Gravity 2=Pressure 1 = Cast Iron or Plastic 2 = Other
23. Other Manure Storage Other NR 112 Waste Source
24.

Drillhole Dimensions

From (ft.)	To (ft.)
surface	83
83	100

Method of constructing upper enlarged drillhole only.

1. Rotary - Mud Circulation
X 2. Rotary - Air
3. Rotary - Foam
4. Reverse Rotary
5. Cable-tool Bit ____ in. dia.
6. Temp. Outer Casing ____ in. dia. Removed?
7. Other

9. Geology

DNR USE ONLY	Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
C	CLAY	Surface	4
L	LIMESTONE	4	42
KN	BLACK SANDSTONE	42	61
GN	GREY SANDSTONE	61	82
IN	WHITE SANDSTONE	82	100

Casing, Liner, Screen Material, Weight, Specification, Manufacturer & Method of Assembly	From (ft.)	To (ft.)
NEW BLACK STEEL, P.E., TAIWAN PIPE ASTM	surface	83

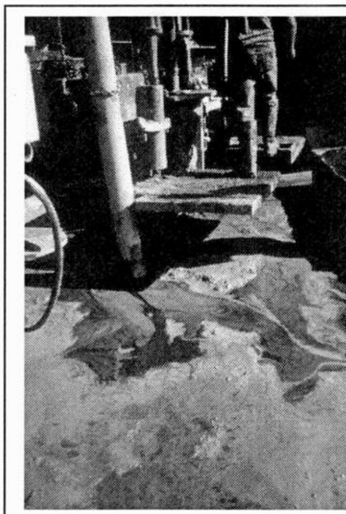
screen type, material & slot size | From | To

10. Static Water Level 52.0 ft. B ground surface A=Above B=Below

11. Pump Test Pumping Level 73.0 ft. below ground surface Pumping at 15.0 GPM 8.00 hrs

12. Well Is: 12 in. A Grade A=Above B=Below Developed? Y Disinfected? Y Capped? Y

5 The Sulfide Cement Horizon (SCH) can sometimes be seen during the drilling of the well. Drillers often report it on Well Construction Reports (see example). The picture shows black sand and mud being returned with the cuttings and



sometimes an oily sheen can be present also. However, the black color is not always present or noticeable.

6 In a subdivision, just southwest of Green Bay, water levels had declined and all the wells in the area had arsenic in the 1000 ppb range. The pH in a number of the wells was around 3. Several of the wells produced acceptable water after being deepened and lowering the pump, but only for short periods of time. All of the homes are now served by municipal water.