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Parameter in Water Wells in
Winnebago and Outagamie
Counties, Wisconsin

Arsenic as a Naturally Elevated Parameter in Water Wells in Winnebago and Outagamie Counties, Wisconsin

by

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ABSTRACT

ARSENIC AS A NATURALLY ELEVATED PARAMETER IN WATER SUPPLY WELLS IN EASTERN WINNEBAGO AND OUTAGAMIE COUNTIES, WISCONSIN

Rebecca S. Burkel

Concentrations of arsenic, ranging from 1.0 to 1200 micrograms per liter (μg/L), were detected in groundwater over a broad geographic region in Outagamie and Winnebago Counties in Wisconsin. The hydrologic and geochemical properties of the area were examined and the source of arsenic determined to be natural. Groundwater collected from two geologic formations, the St. Peter Sandstone and the overlying Platteville/Galena Dolomite, were found to be the principle sources of the elevated arsenic concentrations. These two formations supply most of the drinking water to a large portion of eastern Wisconsin.

Arsenic levels of 10 μg/L or greater were found in 185 of 1037 water supply wells sampled in Outagamie and Winnebago Counties. When arsenic was detected at or above 10 μg/L, arsenic concentrations generally ranged between 10 μg/L and 16 μg/L. These levels are below the NR 140 Wisconsin Administrative code enforcement standard (ES) of 50 μg/L for groundwater but above the 5 μg/L preventative action limit (PAL). The enforcement standard of 50 μg/L for arsenic was exceeded in 37 of 1037 water supply wells sampled in Outagamie and Winnebago Counties. Arsenic was also detected in water supply wells at concentrations below 10 μg/L.

Laboratory chemical analysis of sandstone and dolomite drill cuttings obtained during construction of water supply wells in the area also revealed natural arsenic concentrations ranging from 1.7 to 67 milligrams per kilogram (mg/kg). Water wells containing elevated levels of arsenic varied in depth from 18.3 m (60 feet) to 97.5 m (320 feet). These wells are cased off at varying depths generally within the Platteville/Galena Formation. However, some of the wells with elevated concentrations of arsenic have casings which terminate in the St. Peter Sandstone and the overlying Platteville/Galena Formation is not present. Results suggest that when present, the geologic contact between the St. Peter Sandstone and the overlying Platteville/Galena Formation is the predominant source of elevated arsenic concentrations within groundwater in the study area.

Based on the data gathered from this study an arsenic advisory area for both Outagamie and Winnebago Counties was designated. Guidelines for well drillers and owners constructing new wells within the advisory area were developed to reduce the likelihood of arsenic presence in the water supply. Three wells containing arsenic concentrations exceeding the health advisory were successfully reconstructed or new wells were constructed based on the guidelines developed, which eliminated or substantially reduced arsenic levels in the well water supplies.

Three wells were found within Outagamie County to have an unusually low pH. Preliminary results suggest that the cause for each of these wells unusually low pH is of natural origin induced by the oxidation of pyrite or arsenopyrite, iron sulfide minerals commonly associated with acid mine drainage. In this reaction pyrite is oxidized forming sulfuric acid. The presence of acidic water may cause metals to leach from native rock formations in to the water supply.

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CHAPTER 1 - INTRODUCTION

Statement of the Problem

Approximately 15 percent of the United States population rely on privately owned and operated wells, cisterns, and springs for drinking water (EPA, 1990). Taken from a 1980 census of households occupied year round, an estimated 1,200,000 households were receiving water from public water sources in Wisconsin in 1980 (Lohr, 1985). There were an estimated 519,000 households receiving water from privately owned drilled, dug or other wells in Wisconsin (Lohr, 1985). It is estimated that on average approximately 10,000 new drilled wells are constructed and documented by well drillers each year in Wisconsin. Public water systems have to comply with both federal and state regulations to protect the public health. Private wells are not governed by these federal regulations and are often regulated to a limited degree by the states. The Wisconsin Department of Natural Resources (WDNR) requires that all wells be sampled and analyzed for coliform bacteria after construction. The individual well owner is responsible for the safety of their well water. Often due to the lack of knowledge, the well owner assumes the water to be in good condition. Most private wells have had limited testing, generally only for coliform bacteria and possibly some for nitrate. Private well owners in Wisconsin are not required to monitor their well water, however, the WDNR recommends that all wells be monitored yearly for coliform bacteria and nitrate. Limited awareness of the public about well water and its monitoring has increased the potential for unsuspecting families to be impacted by groundwater contamination by many sources.

Arsenic contamination in water supplies was first identified in Winnebago County, Wisconsin, in 1987, during a feasibility study for a landfill site. The proposed landfill was to be in Vinland Township. Eight private wells, five surface water points, along with numerous monitoring wells were sampled in the area around the proposed landfill site. Results for arsenic (As) analysis exceeded Wisconsin's groundwater preventative action limit of 5 parts per billion (ppb) As in five of the eight private wells sampled. In 1988, the WDNR performed followup sampling and analysis. After sampling all other wells within a 1.6 km (1 mile) radius of the proposed landfill site, they found that 8 of the 22 private wells had levels of 10 ppb As or greater. Also, in 1987, a facility in Clayton Township, approximately 8.0 km (5 miles) further north tested their potable water supply and found high levels of As (75 ppb). There is an active landfill near this facility, but wastes disposed did not contain As. Furthermore, the landfill exhibited no signs of leakage. Several other potable wells were then sampled in the area and one had an As level greater than 10 ppb (17 ppb).

Arsenic presents a potential health concern for individuals supplied by water with elevated arsenic concentrations. Some individuals in the area of concern have not had their water tested for arsenic, therefore their level of risk is unknown. Long term low level exposure to arsenic, a known carcinogen, may cause changes in the skin which may lead to skin cancer. Routine water sampling or sampling just after well construction is generally only for bacteria and does not normally include analysis for arsenic.

Objectives

The objective of this project is to determine the lateral and vertical distribution of naturally occurring arsenic in groundwater and geologic formations. This information is to be used to develop special well casing and well construction criteria for new wells in affected areas.

Funds to meet these objectives were provided in September of 1991 by the Wisconsin Groundwater Fund. This fund was established in 1983 by the Wisconsin Legislature. It is a separate groundwater account which is used to fund groundwater management activities. The fund is continuously replenished through various appropriated fees. Prior studies by the WDNR demonstrated the need for a more extensive investigation of the occurrence of arsenic in private water supplies in Outagamie and Winnebago Counties. Thus, this project was initiated. The work performed by the author was as a WDNR representative. On occasion other WDNR employees accompanied the author to aid in the data collection.

CHAPTER 2 - OVERVIEW OF ARSENIC

Properties

Arsenic is a naturally occurring element in the Earth's crust and is found in all living things. It ranks 20th in abundance in the Earth's crust and 12th in the human body. Arsenic is present in the Earth's crust in concentrations ranging from parts per billion to parts per million with the global average concentration being 1.8 ppm. Naturally occurring arsenic is found primarily in sedimentary and igneous rocks (Irgolic, 1982) and tends to be associated with sulfide ores, volcanic or hydrothermal activities.

Arsenic is classified as a metalloid. In its elemental state arsenic is silver-gray or tin-white in color. Elemental arsenic is very insoluble in water and is nearly odorless and tasteless (Elmsley, 1985). Its atomic number is 33, atomic weight 74.92, density 5.727 g/cm ^{3}, and melting point 817 °C.

Water soluble arsenic compounds may occur in both organic and inorganic forms. Arsenic can be altered into one or more forms by biological and/or chemically mediated reactions. The form in which arsenic is found in water is dependent on the Eh, pH, organic content, suspended solids, dissolved oxygen, and other elements in the water (Eisler, 1988). Arsenic exists primarily as a dissolved ionic species in water (Eisler, 1988). Arsenic associated with particulates accounts for less than one percent of the total arsenic in waters (Eisler, 1988). It can be found in four oxidation states (+5, +3, 0, -3) in aquatic systems. Arsenic is rarely found in the elemental state in water and the -3 state only at very low Eh values (Eisler, 1988). Common forms of arsenic found in natural waters are arsenite, arsenate, methanearsonic acid, and dimethylarsinic acid (Eisler, 1988). Arsenate [As^{+5}] and arsenite [As^{+3}] are the most common forms of arsenic found in groundwater. The most toxic form of arsenic is the arsenite form (Eisler, 1988). Pentavalent arsenic, the most common species in water, is favored under conditions of high dissolved oxygen (high Eh) and basic pH (Eisler, 1988). Lower Eh conditions favor the presence of arsenites and arsenic sulfides (Eisler, 1988).

Arsenic in various inorganic or organic forms may be found in the air, water, or soil. Arsenic enters the environment through natural processes or via human activity. Presently, anthropogenic sources are thought to contribute three times more arsenic than natural sources (Eisler, 1988). Some anthropogenic sources of arsenic are fossil fuel combustion, pesticide use, copper and lead smelting, and improper disposal of arsenic compounds. Natural forces that influence the presence of arsenic are volcanic emissions, and weathering of arsenic containing rocks, arsenopyrite (FeAsS) and realgar (AsS). Arsenic tends to exist naturally with sulfide ores of iron, nickel, and cobalt (Eisler, 1988).

Uses

Arsenic compounds have been used historically for many different purposes such as in medicine, pesticides and herbicides. Both inorganic and organic arsenicals have been used for centuries. Arsenic compounds have been used for medicinal purposes since the time of Hippocrates, ca. 400 B.C. (Eisler, 1988), with legend having it that Hippocrates used an arsenic sulphide ore, realgar as a remedy for sores (Elmsley, 1985). Organic arsenicals have been used for the treatment of syphilis, yaws, amoebic dysentery, and rypanosomiasis (Eisler, 1988).

From the 1200's to the 1650's, arsenic found its way to homicidal use (Eisler, 1988). White arsenic or arsenic trioxide was the most common form used for this purpose. It may give a slightly sweet taste to no taste at all (Elmsley, 1985). Arsenic trioxide is only slightly soluble in water, however, a solution that is saturated can easily contain a lethal dose. In World War II arsenic was used as a ingredient in a poison gas called, lewisite (Eisler, 1988).

Arsenical drugs are still used today in medicine and animal husbandry. Some arsenic based drugs are used to treat certain tropical diseases, such as African sleeping sickness and amoebic dysentery (Eisler, 1988). Arsenical drugs are also used in veterinary medicine to treat parasitic diseases such as filariasis in dogs (Eisler, 1988). Arsenic is known for it use in the pig and poultry industry; it promotes animal growth (Eisler, 1988). These industries use a substance called roxarsone. Roxarsone-fed pigs and hens tend to gain weight 3 per cent faster, therefore, its use is cost effective for the production of swine and poultry (Elmsley, 1985).

Arsenic compounds have been used both historically and presently as pesticides and herbicides. Arsenic combined with copper was used to control the Colorado beetle in the late 1800's (EPA, 1982). Arsenic was also combined with lead and used to control the gypsy moth (EPA, 1982). Inorganic arsenicals such as arsenates of calcium, copper, lead, and sodium and arsenites of sodium and potassium have been used for centuries as insecticides, herbicides, and desiccants (Eisler, 1988). Sodium arsenite has been used for aquatic weed control and as weed killer along roadsides. Calcium arsenates have been used by cotton and tobacco growers against insects like the boll weevil (Eisler, 1988). Lead arsenate has been used to control insects on fruit trees, and the codling moth in apple orchards (Eisler, 1988). By the 1920's arsenical pesticide use had grown and numerous poisonings from treated fruit and vegetables encouraged the search for other pesticides (Eisler, 1988). Today, arsenic compounds remain in use in large quantities as insecticides, herbicides, desiccants, wood preservatives and growth stimulants for plants and animals. Manufacturers of metal, glass and electronic components, and medicinal and veterinary applications utilize smaller amounts of arsenic (Eisler, 1988).

Human activities have increased arsenic concentrations in certain areas and hence the potential for human exposure has increased. Some human activities elevating arsenic concentrations in the environment are: (1) the smelting and refining of gold, silver, copper, zinc, uranium, and lead ores; (2) the combustion of fossil fuels; (3) careless or extensive use of arsenical pesticides; (4) the manufacture of glass and (5) the placement of water wells in naturally arseniferous rock (Eisler, 1988). The largest anthropogenic source of arsenic in the environment is from agricultural applications (Eisler, 1988). All of these anthropogenic sources can be leached and cause elevated arsenic levels in groundwater.

Health Concerns

Since arsenic is ubiquitous, it is important to understand that humans and animals are continually exposed to it. The average person in the United States is estimated to consume 45-50 μg/day of total arsenic, excluding that from tap water (Smith et al, 1992). Therefore, arsenic is continually replenished in our bodies through our diet, primarily from seafood, meat and poultry (80%), and grains and cereals (17%) (Smith et al, 1992).

Arsenic enters the body through three main routes. It may be ingested through food or water consumption, inhaled via the air, or absorbed through the skin and mucous membranes (Eisler, 1988). For most people, the largest source of arsenic comes from food with smaller amounts coming from drinking water and air.

Arsenic can enter these intake sources via natural and man-made routes. Arsenic can be introduced into food through pesticide use and animal feed. Drinking water can contain arsenic from natural mineral deposits, placement of water wells in naturally arseniferous rock, pesticide use, and improper disposal of arsenical compounds. The principle source of arsenic in air in the U.S. results from the combustion of fossil fuels (Eisler, 1988).

Adverse health effects from arsenic consumption are highly dependant on many factors. These factors include the amount or dose of arsenic ingested, the duration of arsenic ingestion, and the chemical form of arsenic present. The toxicity of arsenicals seems to be directly related to the solubility of the specific chemical species in water and body fluids (Eisler, 1988). In general the species toxicity diagram of arsenic from greatest to least toxic follows the order:

Arsines > Inorganic Arsenites > Organic Trivalent Compounds > Inorganic Arsenates > Organic Pentavalent Compounds > Arsonium Compounds > Elemental Arsenic

Most Toxic ————————————————> Least Toxic

Elemental arsenic is the least toxic form and the least soluble form. Inorganic arsenites and arsenates are more toxic and more soluble in body fluids and water than is the elemental form of arsenic. Arsenate, [(+5) oxidation state] is less toxic than arsenite, [(+3) oxidation state] (Frank and Clifford, 1986). Arsenite, however, is more soluble in body fluids than arsenate which causes it to be more toxic. However, the body has mechanisms which can convert arsenic from the +5 oxidation state to the +3 oxidation state giving rise to the more toxic form (Eisler, 1988). The major toxic effect of arsenic is its ability to inactivate sulfhydryl containing enzyme systems (Eisler, 1988, Marquis, 1989).

Once arsenic enters the body, the gastrointestinal tract and lungs begin to absorb it (Marquis, 1989). Cells accumulate arsenic through an active transport system (Eisler, 1988). Skin absorption of arsenic is much slower than that of the gastrointestinal tract and lung absorption (Marquis, 1989). Within 24 hours of ingestion, arsenic is distributed to all body tissues but it is more concentrated in the liver, kidney, lung, and spleen (Marquis, 1989). Most arsenicals are rapidly excreted from the body in the urine during the first few days after ingestion (Eisler,1988). By the second week after ingestion, some arsenic is deposited in the skin, hair, and bones (Marquis, 1989). Inorganic arsenic, however, does not enter the brain. Apparently the blood-brain barrier prevents the movement of arsenic to the brain. Arsenic does cross the placenta, however, and can effect the fetus.

Between one and twelve hours after acute poisoning, symptoms may appear (Marquis, 1989). The most common symptoms seem to be related to the gastrointestinal tract (Marquis, 1989). These symptoms include burning of the throat, difficulty in swallowing, nausea, and severe abdominal pain. Other symptoms include profuse watery and bloody diarrhea and bloody vomiting (Marquis, 1989). Vomiting can appear anywhere from 20 minutes to 12 hours after ingestion of arsenic depending upon the amount of food present in the stomach at that time (Elmsley, 1985). Food generally slows the absorption of arsenic (Elmsley, 1985). The cardiovascular system may respond anywhere from 30 to 120 minutes after ingestion (Marquis, 1989). The symptoms may be hypotension (low blood pressure), cyanosis, (a bluish or purplish coloration of the skin) or electrocardiogram changes (Eisler, 1988, Marquis, 1989). The kidneys may be effected causing blood, proteins, and sugar to appear in the urine (Marquis, 1989). The central nervous system can also be threatened by the arsenic causing symptoms such as headaches, delirium, muscle spasms, weakness, numbness and tingling in the arms and legs, coma, and convulsions (Eisler, 1988, Marquis, 1989). Death may occur within 36 to 96 hours of digestion (Elmsley, 1985).

Chronic poisoning by arsenic can cause heart failure, edema, blackfoot disease, anorexia, nausea, diarrhea, weight loss, and cirrhosis of the liver (Eisler, 1988, Marquis, 1989). Some chronic effects on the nervous system include numbness and tingling in the legs and arms, lethargy, weakness, and paralysis of the legs (Eisler, 1988, Marquis, 1989). Hyperpigmentation of the skin, appearance of small corns on the palms, soles, and trunk may appear along with hoarseness, hair loss, and thickening of the skin can also be signs of chronic arsenic poisoning (Eisler, 1988, Marquis, 1989).

Arsenic is considered to be a carcinogen, teratogen and mutagen (Eisler, 1988, Marquis, 1989). When ingested, arsenic can cause skin tumors and when inhaled, it may cause lung tumors (Meyer, 1989). Arsenic can cross the placental barrier and produce fetal abnormalities and death in many species (Eisler, 1988). Chronic arsenic toxicity has been associated with chromosomal abnormalities (Eisler, 1988). Long term effects of exposure to low levels of arsenic can increase the risk for skin cancer, and may cause digestive problems.

Arsenic exposure can be identified by analysis of blood, urine, fingernails or hair. Blood is a useful indicator of only very recent exposures (Eisler, 1988). Most arsenic is cleared from the blood within a few hours after ingestion (State of Wisconsin Toxic Chemical Series, 1990). Urine tests are also often used to indicate recent exposure to arsenic. Most absorbed arsenic is eliminated through the urine within a few days after exposure (Eisler, 1988). The arsenic level in hair and nails may be a useful indicator to measure chronic exposure because it tends to accumulate in the hair and nails (Eisler, 1988). This test, however, is not conclusive evidence of a high dose of arsenic because arsenic can come from both internal and external sources (Eisler, 1988).

Treatment for arsenic poisoning depends on the dose acquired. The initial concern for the treatment of acute arsenic poisoning is to remove the arsenic from the gastrointestinal tract. This may be accomplished by vomiting, or consuming activated charcoal (Marquis, 1989). Arsenic is opaque to radiation and can be seen on x-ray film (Marquis, 1989). The abdomen can be x-rayed to see if there is still a presence of arsenic in the gastrointestinal tract (Marquis, 1989). The next treatment consists of using a chelating agent such as BAL (British Anti-Lewisite or dimercaptopropanol) to enhance excretion of the absorbed arsenic from the body (Carlson, Ellis, and McCann, 1986). Three to five mg/kg of BAL is given to the patient every four hours until the gastrointestinal symptoms have subsided and the absorption of arsenic has ceased (Marquis, 1989). Some literature suggest that selenium may reduce arsenic's carcinogenic effects (Carson, Ellis, and McCann, 1986).

At the present time the drinking water standard for total arsenic is 50 μg/L. This was established by the Safe Drinking Water Act (SDWA) in 1986. Normally arsenic levels are not tested in private wells unless specifically requested. But when arsenic levels are determined and concentrations exceed the drinking water standard, users of the well are informed that the water should not be used for drinking or food preparation purposes. The reason is that chronic exposure to arsenic in groundwater may produce harmful side effects, especially skin cancer, for those relying on arsenic contaminated groundwater for their drinking water (EPA, 1982).

Long-term low-level human exposure to arsenic has occurred and continues to occur at some homes in Outagamie and Winnebago Counties supplied by potable water containing elevated arsenic concentrations. Treatment for long-term low-level arsenic exposure is to remove the source of arsenic. After stopping arsenic intake most symptoms disappear. To date at least two families in the area attribute various health symptoms to arsenic ingestion and the disappearance of symptoms to the discontinuation of using arsenic contaminated water. Proper means of avoiding arsenic exposure are to purchase bottled water for consumption and food preparation, to use an approved treatment device for the removal of arsenic from the water supply, or to reconstruct an existing well or to drill a new well.

Additional arsenic exposure can also occur through airborne inorganic compounds in the workplace. This exposure is regulated by Occupational Safety and Health Administration (OSHA). The most common cause of arsenic exposure in the workplace is from inhalation of inorganic arsenic compounds (Meyer, 1989). The threshold limit value over a period of eight hours is 5 $\mu g/m^3$. The Department of Transportation regulates the transportation of arsenic compounds. All compounds must be labeled as a poison and they are to be kept away from food items.

Geology of Outagamie and Winnebago Counties

Knowledge of the geology of both counties is important because the arsenic found in the groundwater is believed to be of natural origin from the dissolution of arsenic containing rock. The geology of both Outagamie and Winnebago Counties are described in publications by LeRoux (1957) and Olcott (1966) in the Geological Survey Water-Supply Papers 1421 and 1814, respectively.

The crystalline rocks of the Precambrian age underlie all of Outagamie and Winnebago Counties. The Precambrian crystalline rocks are composed primarily of granite. The Precambrian rock impedes the downward movement of groundwater from the overlying Cambrian sandstones (Olcott, 1966). The Precambrian rock yields little to no water to wells drilled into it; water is only obtained from the fractures within it. Little is known about the depth of the Precambrian crystalline rock. The Precambrian surface is thought to be relatively smooth, dipping to the southeast at a rate of about 3.8 m/km (20 ft/mi) (Olcott, 1966). Olcott, however, mentions the presence of ridges or knobs in the Precambrian surface which, in places, may ascend several hundred feet (Olcott, 1966). Furthermore, Olcott states that the presence of knobs or ridges of this nature could hinder the horizontal movement of groundwater through the overlying Cambrian sandstones. Where highs occur on the Precambrian surface the thickness of the overlying sandstones is reduced (Olcott, 1966).

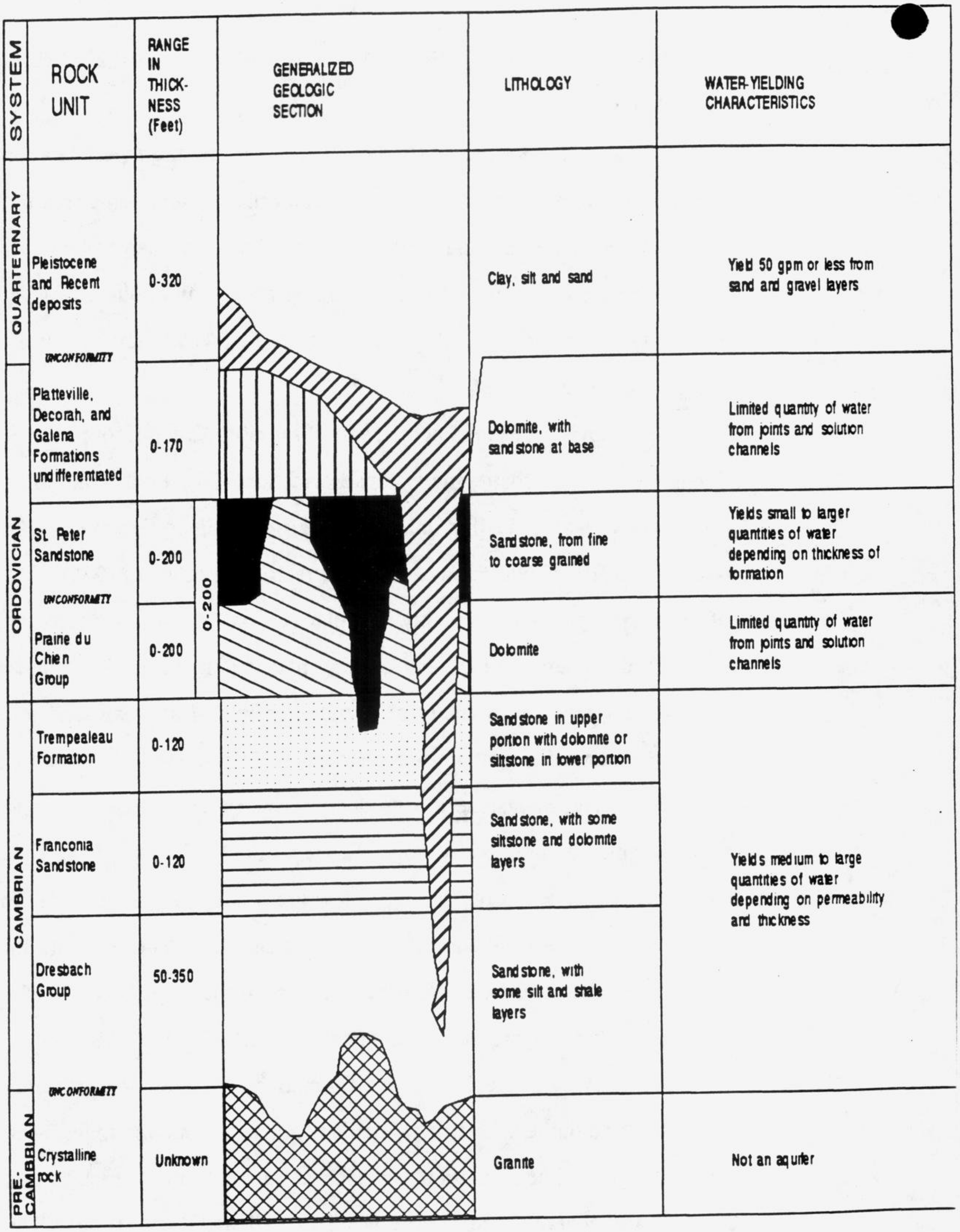
Above the Precambrian crystalline rocks lie the Cambrian and Ordovician rocks which comprise what is collectively referred to by Olcott and LeRoux as the Sandstone aquifer. The Sandstone aquifer is labeled as such because, excluding the upper dolomite unit, all the units are hydraulically interconnected even though they are of different lithology and permeability (Olcott, 1966). These rocks are made up primarily of sandstone but also contain some limestone. The Cambrian and Ordovician units generally dip at the same rate as the underlying Precambrian rock in a southeastward direction. Figure 1 is a geologic cross-section of Outagamie and Winnebago County.

The Cambrian sequence rests on the irregular and highly eroded surface of the Precambrian rock (Olcott, 1966). The Cambrian System comprises three formations, the Trempealeau, Franconia, and Dresbach. The Cambrian System is made of fine to coarse grained sandstone. These sandstones are a major source of groundwater especially for municipal wells. The surface of the Cambrian System is fairly regular and smooth (Olcott, 1966).

The Ordovician System contains the Prairie du Chien Group, the St. Peter Sandstone, and the Platteville/Galena Formation. The Prairie du Chien is a relatively unproductive water yielding unit. The Prairie du Chien Group consists of dolomite with thin layers of white sandstone and green shale (Olcott, 1966). The upper surface of the Prairie du Chien is highly irregular (Olcott, 1966). A limited amount of water is found in fractures, joints, and bedding planes (Olcott, 1966). The Prairie du Chien has a lower permeability than that of the underlying Cambrian sandstones and it may hinder the vertical migration of groundwater (Olcott, 1966).

The St. Peter Sandstone is a productive water-yielding unit. It consists of fine to coarse-grained dolomitic sandstone (LeRoux, 1957). The St. Peter Sandstone rests on the Prairie du Chien Group filling in low areas but it is absent on the Prairie du Chien highs (Olcott, 1966). Water yields from the St. Peter Sandstone are limited by the presence of shale and by the limited thickness of the formation. Thicknesses range from 0 to 30.5 m (0 to 100 ft) in the study area (Thwaites, 1961).

The overlying Platteville/Galena Formations are composed of sandy-gray to bluish-gray dolomite with fine to medium grained sandstone found near the base (Olcott, 1966). The formations are located generally in the eastern part of both counties and generally yields little water to wells (LeRoux, 1956). The water that is present is found in joints, bedding planes and fractures within the rocks. The



SYSTEM	ROCK UNIT	RANGE IN THICKNESS (Feet)		GENERALIZED GEOLOGIC SECTION	LITHOLOGY	WATER-YIELDING CHARACTERISTICS
QUATERNARY	Pleistocene and Recent deposits	0-320			Clay, silt and sand	Yield 50 gpm or less from sand and gravel layers
	UNCONFORMITY					
ORDOVICIAN	Platteville, Decorah, and Galena Formations undifferentiated	0-170			Dolomite, with sandstone at base	Limited quantity of water from joints and solution channels
	St. Peter Sandstone	0-200	0-200		Sandstone, from fine to coarse grained	Yields small to larger quantities of water depending on thickness of formation
	UNCONFORMITY					
	Prairie du Chien Group	0-200			Dolomite	Limited quantity of water from joints and solution channels
CAMBRIAN	Trempealeau Formation	0-120			Sandstone in upper portion with dolomite or siltstone in lower portion	Yields medium to large quantities of water depending on permeability and thickness
	Franconia Sandstone	0-120			Sandstone, with some siltstone and dolomite layers	
	Dresbach Group	50-350			Sandstone, with some silt and shale layers	
	UNCONFORMITY					
PRE-CAMBRIAN	Crystalline rock	Unknown			Granite	Not an aquifer

Figure 1. - Generalized cross-section of rock units in Outagamie and Winnebago Counties, Wi[illegible]nsi

(From Olcott, 1966).

Platteville/Galena has a lower permeability than the St. Peter Sandstone below and therefore may cause artesian conditions within the underlying unit (Olcott, 1966). The groundwater flows in a southeasterly direction across both counties (Figure 2).

A map of the bedrock geology of both counties is found in Figure 3. The maps of the geology of Winnebago and Outagamie Counties provided by Olcott and LeRoux, collectively contain a discrepancy at the interface of the two (Figure 3). The St. Peter Sandstone should follow continuously down through Winnebago and the Prairie du Chien should also extend continuously through Winnebago County. This discrepancy is transferred as found in Geological Survey Water Supply Papers 1814 and 1421. The discrepancy in this area is approximately 1 to 2 km (1 mile).

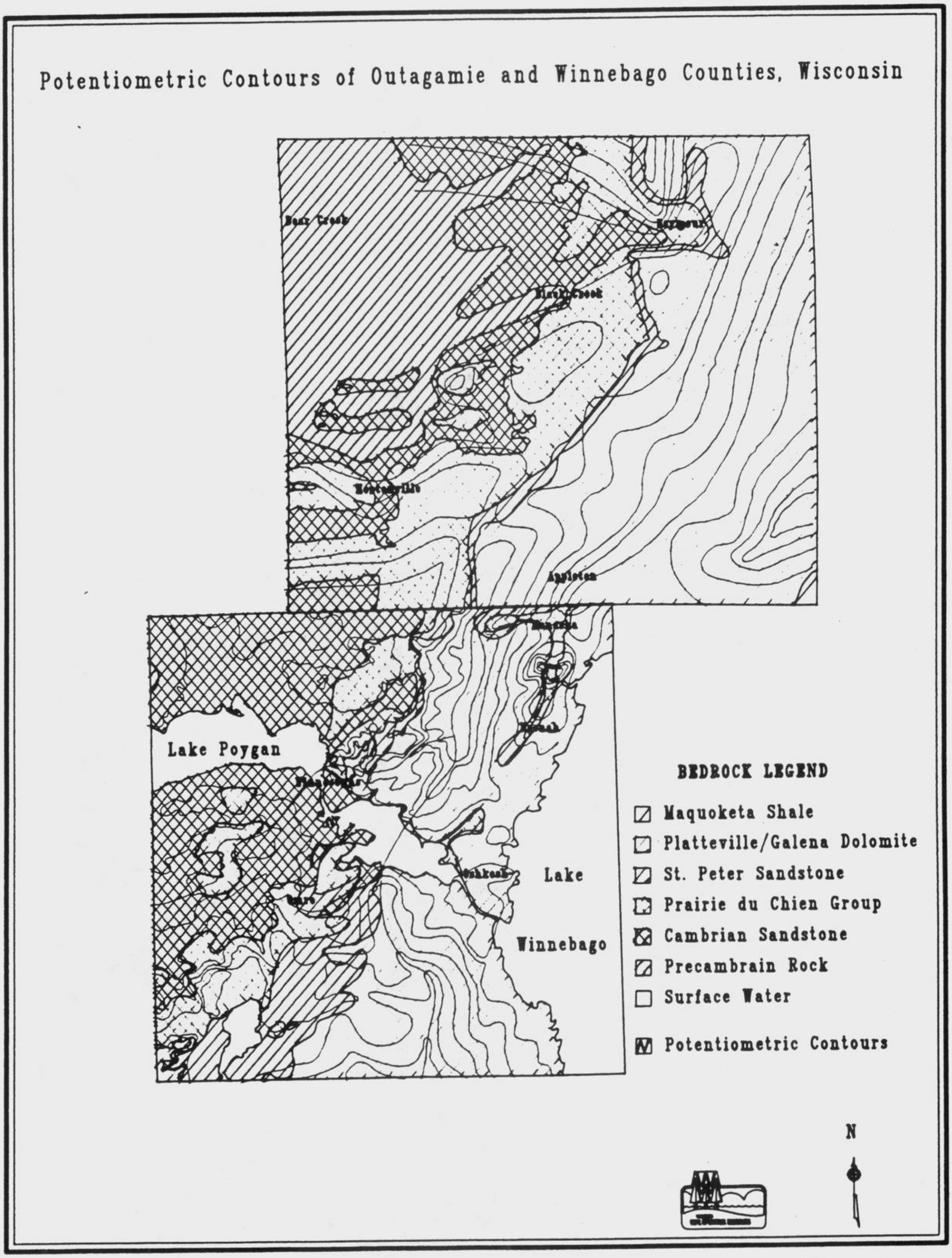


Figure 2. Potentiometric Contours of Outagamie and Winnebago Counties. Wisconsin

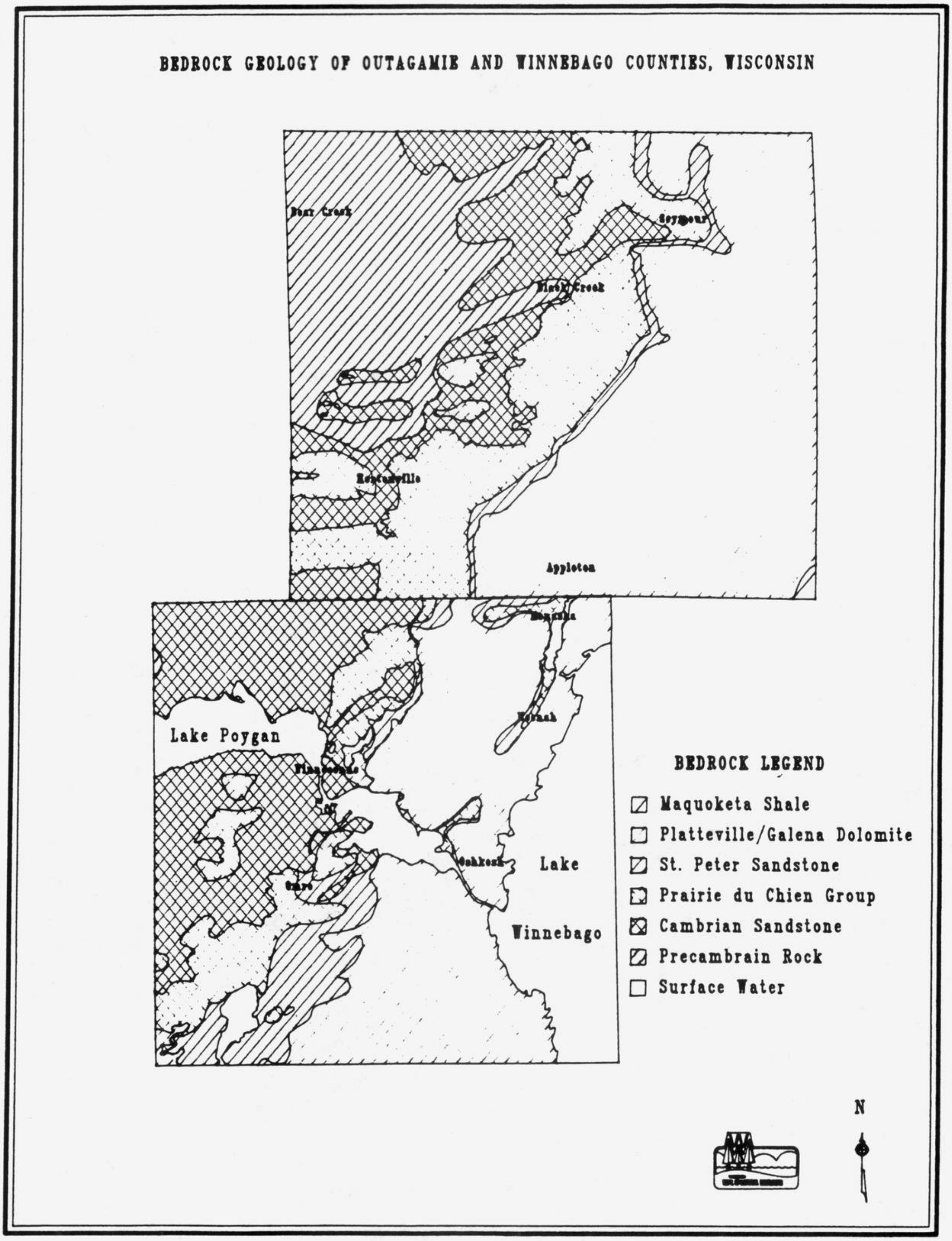


Figure 3. Bedrock Geology of Outagamie and Winnebago Counties. Wisconsin

CHAPTER 3 - METHODOLOGY

Water Sample Collection and Analysis

WDNR Sample Population

The objective of the initial sampling program was to determine to what extent arsenic contamination occurs in private wells within Outagamie and Winnebago Counties. Sampling sites were selected based on the availability of well construction reports, the ability to contact the present home owner, the location of the well, and the presence or absence of St. Peter Sandstone. Based on the lithology identified from well construction reports, wells were selected for sampling. After selection of specific wells as potential sample locations, the owners were contacted. Permission was requested verbally over the telephone to collect a water sample from their well. The owner was given the option to refuse permission to sample his/her well. If the owner declined permission, the well was not sampled. If the owner chose to cooperate, a mutually convenient time was set up to collect the well water sample. If sample analysis revealed an elevated level of arsenic in a specific locale, other wells in the immediate vicinity were selected and sampled. However, not all existing wells close to a well with a high level of arsenic were sampled because of cost constraints. The study objective was to determine over what geographic extent arsenic existed in private water supplies and whether the presence of arsenic was influenced by human or natural sources.

Samples were collected following guidelines set up in the 1987 Wisconsin Department of Natural Resources Groundwater Sampling Procedures Field Manual and the 1987 Wisconsin Department of Natural Resources Groundwater Sampling Procedures Guidelines both developed by Lindorff, Feld, and Connelly. Briefly, the sample collection procedures are as follows: All samples were collected from a cold water tap that did not receive water from the plumbing line after a treatment device e.g. a water softener or filter. This requirement was confirmed either visually at the time of sampling or verbally with the owner prior to sampling. Samples that could only be obtained from water lines after these devices were documented. Most samples were collected at the sample tap directly after the pressure tank, or at an outside faucet. Samples were collected after flushing the water supply tap for three to five minutes or after the pump started running. This procedure was used to ensure the water sample represented *in situ* groundwater and not water standing in the pipes. All samples were collected in appropriate sample containers supplied by the Wisconsin State Laboratory of Hygiene (WSLH). The samples were preserved and labeled as per the requirements by the WSLH. Preservation methods and sample bottle requirements for analysis are listed in Appendix I. All samples were sent to the WSLH for arsenic analysis and other metals or parameters if indicated. The methods used by the WSLH for individual analysis are documented in Appendix I. Note that methods used by the WSLH changed over the course of this study and therefore, the detection limits for arsenic may differ from well to well.

After receiving analytical results from the laboratory, well owners were notified of their results via a form letter. If the As concentration exceeded the health advisory, the form letter contained (1) an advisory notice not to drink the water or use it in food preparation, (2) telephone numbers of individuals from various agencies to contact for more information about arsenic, (3) information about cost sharing programs available to them and (4) telephone numbers of individuals to contact about reconstruction of their existing well or drilling a new well. If their As result was below the health advisory they were also notified.

WDNR and Department of Health Sample Populations

The WDNR along with the Departments of Health for Outagamie and Winnebago Counties initiated a second well water sampling program for private homeowners in affected areas to have their water tested for arsenic. A news release was distributed to all major media sources to inform the public of the potential for arsenic contamination in wells within a specific geographic area. The initial area of potential arsenic contamination was defined using prior results. The area was described using major roads as division lines (Figure 4). These arbitrary lines were general and not meant as a final determination as to where arsenic was or was not present. Instead, the lines provided a communicable boundary around an area to indicate a greater likelihood of arsenic impact to the public. When these boundaries were selected, it was recognized that arsenic might exist in wells outside these boundaries.

The Outagamie and Winnebago County Health Departments provided arsenic sample kits to interested private homeowners from October 5 to October 19, 1992, for a fee of $ 20.00. When obtaining a sampling kit, the owner was given a unique identification number, a corresponding uniquely numbered identification pin, a well information survey, and an arsenic information packet. The well owner then placed the pin on a map corresponding to the location of the well to be sampled. The private homeowner also filled out the well information survey to aid WDNR personnel in finding the corresponding well log. The well location and well information survey was used by the WDNR to obtain a well construction report which should have been filed by the well driller after well construction. Well construction reports filed by well drillers can be found in files located at WDNR offices. In some instances well construction reports are not available because they were not filed by the well driller or location information about the well is incorrect.

The arsenic information packet supplied by the Health Departments and the WDNR explained various health effects of arsenic, where the arsenic problem had been identified, the possible cause of arsenic contamination, approved treatment units available for removal of arsenic from well water and how to take a sample for arsenic. After homeowners collected the water samples, they returned the samples to the County Department of Health. The Department of Health then brought the

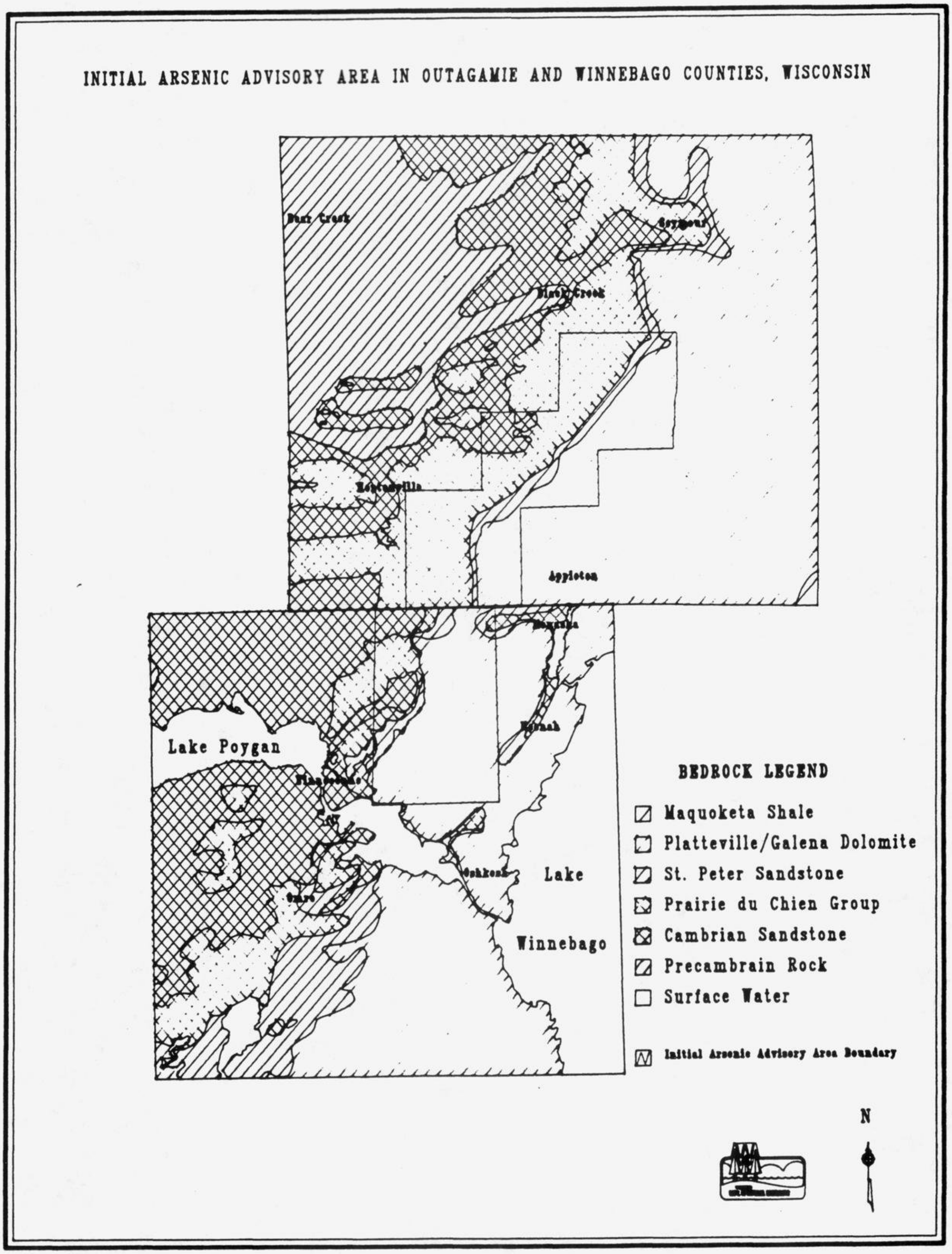


Figure 4. Initial Arsenic Advisory Area for Outagamie and Winnebago Counties, Wisconsin

samples to Badger Laboratory in Appleton, Wisconsin, for arsenic analysis. Badger Laboratories analyzed each sample by high temperature graphite furnace atomic absorption methods. They reported that this method had a 2 μg/L lower detection limit. All homeowners who participated in the arsenic sampling were advised of their As result via a postcard sent from the respective county health department. Private homeowners who did not want to participate in the arsenic sampling program but desired to know more about arsenic contamination were provided with the arsenic information packet by either the WDNR or county health departments free of charge.

Data Handling - Geographic Information System (GIS)

The Geographic Information System (GIS) is a computer software program designed to handle large quantities of data for particular geographic regions. GIS is useful to present geographical data in a detailed map format. In this study water quality and well location data from wells sampled for arsenic was compiled and used to aid in interpretation of arsenic contamination. Resource maps that were used by the WDNR as base layers to produce the arsenic contamination maps were those supplied in the reports by LeRoux, 1957 and Olcott, 1966. Both sources contained maps of bedrock geology and piezometric contours. The bedrock geology and piezometric surface map for Winnebago County, Water-Supply Paper 1814, Plate 1, was published in 1963. This map was digitized for the GIS at a scale of 2.54 cm (1 in) equals 1.61 km (1 mi) using PC ARC/INFO. The bedrock geology for Outagamie County was digitized from Water-Supply Paper 1421, Plate 2, published in 1954 at a scale of 1.91 cm (3/4 in) equals 1.61 km (1 mi). The piezometric surface for Outagamie County was digitized from Water-Supply Paper 1421, Plate 5 published in 1954 at a scale of 1.91 cm (3/4 inch) equals 1.61 km (1 mi). Since the potentiometric surface contours were mapped in the 1950's and 1960's, the potentiometric surface may not be the same today due to potential drawdown from water consumption and precipitation changes. Road and hydrology information for Outagamie County was received from the Outagamie County Health Department. The Winnebago County road network was received via digitizing of topographic maps from the WDNR, Madison. All well locations were digitized from topographic maps and data entered using the software package Paradox.

Geophysical Well Investigation Methods

Inflatable Packer Test

Packer tests are used to isolate and sample specific subsurface water-bearing zones within a well. Thus, these tests can be used to determine potential areas in the subsurface causing poor water quality. The packer assembly often consists of two inflatable packers and a water pump (Chapter 4, Figures 8 and 10). The goal of the packer test is to pump water from between the packers to obtain a representative composite of the water that enters the well from a specific zone. Thus, the quality of the water pumped from the entire well can be compared to water pumped from distinct zones of the well to identify variations in water quality.

The integrity of the packer seals are important and is typically monitored throughout each packer test by a water level indicator. If the water level above the top packer were to fluctuate it would indicate a possible faulty top packer seal. If the packer assembly was not sealed properly the water obtained from the packer test would not be a true representation of the water quality or quantity that would be received from that portion of the formation. The ability to monitor the packer seals is based on the design of the packer assembly. Packer tests were conducted at the Spreeman and the Olson wells. Due to the type of packer assembly used by Layne-Northwest, the contractor conducting the Spreeman packer tests, the integrity of the bottom packer seal could not be monitored. During each of the packer test intervals at the Spreeman site, Layne-Northwest personnel indicated that there were no fluctuations in water levels above the packer assembly. This observation suggests that the upper packer was sealed properly. The design of the packer assembly used by Luisier Well Drilling, the contractor at the Olson site, allowed monitoring the integrity of both packer seals. Water samples were only collected from the packer tests that had confirmed the integrity of packer seals by water level measurements above and below the packer assembly with little fluctuation during pumping.

Unused water pumped from all packer test intervals at each site was collected in a large holding tank for later disposal. When the large container of wastewater was full, it was dumped in an approved nearby sanitary sewer. Approval for disposal was obtained by the WDNR for both the Spreeman and Olson packer testing sites.

Caliper Log

A caliper log is a graphical representation of the diameter (shape) versus the depth of the borehole. The caliper log can be used to determine the presence of fracture patterns within limestones and sandstones and caving or erosion in the borehole in a particular geologic formation. This information can be used to determine if a packer assembly would properly seal when installed. Caliper logs are obtained by using a mechanical caliper to measure differences in borehole diameter with depth. The mechanical device usually consists of a probe with three adjustable arms. The measurements are obtained from three arms pushing against the side of the borehole. The movement of the arms is transformed into an electrical output which is translated to variations in the diameter of the borehole. A caliper log of the Spreeman well was obtained on February 3, 1993, by Layne-Northwest over the entire well. The caliper results from Layne-Northwest are found in Appendix II. Layne-Northwest interpreted the results of the caliper log to indicate that the well had no abnormality that would result in a poor seal of the packer assembly.

Gamma-ray Log

A gamma-ray log of a borehole is a graphical representation of the natural gamma-ray radiation from radioactive elements in subsurface formations. Some formations contain greater concentrations of radioactive materials, such as uranium, thorium, and the radioactive isotope of potassium, than others. These radioactive materials emit gamma radiation spontaneously. Most rocks contain some radioactivity, with metamorphic and igneous rocks containing more than sedimentary (Rider, 1986). Clays and shales tend to contain more radioactive elements than sandstones and limestones (Driscoll, 1986). Gamma-ray logs can be obtained from wells with or without casing. The casing absorbs only negligible amounts of radiation. Gamma-ray loggers consist of a scintillation counter, gamma-ray detector. The gamma-ray log is a plot of relative emission of gamma-rays, often measured in counts per second, versus depth. Gamma-ray logs may be used qualitatively to determine formation changes and lithology (Rider, 1986). A gamma-ray log of the Spreeman well was performed by Layne-Northwest on February 3, 1993, to determine transitions between geologic formations in the well. The gamma-ray logger used by Layne-Northwest at the Spreeman well measured the time (seconds) to collect a specific number of counts versus depth. Thus, a high number of seconds is associated with a low rate of emission of gamma-rays. A gamma-ray reading was taken every 0.6 m (2 ft) throughout the entire well column. The results of the gamma-ray log from the Spreeman well are in Appendix III.

Packer Test Locations

The Spreeman and Olson wells were chosen for packer testing. Both the Spreeman well and the Olson well were chosen for packer testing based on the depths of their wells and the concentration of arsenic in their well water. The depth of most private wells in Outagamie and Winnebago Counties typically range between 36.6 m to 48.8 m (120 to 160 ft) below surface. Since the Spreeman and Olson wells were unusually deep, they allowed access to more subsurface formations. The Spreeman well was 97.8 m (321 ft). It also contained the highest recorded arsenic concentration at the time of site selection (470 μg/L) and an unusually high iron concentration (280 mg/L). Furthermore, the owner was cooperative. The Olson well was 91.4 m (300 ft) deep, had a high arsenic concentration of 1200 μg/L and a high iron level of 87 mg/L. This was the highest arsenic concentration found in a private well in Outagamie County. Furthermore, the Department of Health and Social Services of Outagamie County stated that the Olson's seemed to exhibit symptoms associated with chronic arsenic poisoning.

The Spreeman well was to be returned to its original state after performing the packer test. Before any geophysical procedures were run, the Spreeman well was sampled on February 3, 1993, for bacteria from the sample tap located next to the pressure tank. Both a WDNR representative and a Layne Northwest representative collected a water sample for bacteria analysis. This was to ensure that the well would be returned to its initial state after packer testing. Once the bacteria test was collected, the well was opened and the pump was dismantled by Layne-Northwest on February 3, 1993. Packer testing of the Spreeman well began on February 4, 1993, by Layne-Northwest. A diagram of the packer assembly used by Layne-Northwest is shown in Chapter 4, Figure 8.

The Olson well was to be reconstructed to a useable state following WDNR regulations based on packer testing results. Luisier Well Drilling began packer testing on March 17, 1993. The well was reconstructed and put back to normal operation soon thereafter. A diagram of the packer assembly used by Luisier Well Drilling is shown in Chapter 4, Figure 10.

Packer Testing - Water Sample Collection and Analysis

Packer tests were performed on both the Spreeman and Olson wells to identify the potential zones of poor water quality. Gamma-ray logs and caliper logs were performed on the Spreeman well to define subsurface lithology of the well. Subsurface information below 36.6 m (120 ft) was not available for the Spreeman well because a reconstruction form was not filled out by the well driller. Gamma-ray logs and caliper logs were not run on the Olson well because the subsurface lithology of the well was known from recent drilling operations.

The water samples were collected according to WDNR guidelines. All bottles, preservation methods, and labeling methods used were those required by the WSLH. Packer test water samples were collected from a brass tap located directly above the packer assembly prior to disposal to a holding tank. All water samples were sent to WSLH for appropriate chemical analysis. The analytical methods used by the WSLH are shown in Appendix I.

All packer test water samples were taken after 10 minutes of pumping from the isolated interval. This was done to obtain a representative *in situ* sample of groundwater from the interval within the aquifer. Water from each packer test was tested for field pH, field temperature, and arsenic. Some of these samples were later analyzed for cadmium, copper, manganese, and zinc by the WSLH. Additional chemical analysis of these samples were performed due to the unusual composition of the Olson well water. The Olson well contained elevated levels of cadmium, copper, manganese and zinc.

Drill Cutting Analysis

Drill cuttings can be used to determine zones where minerals potentially contribute to poor water quality. Groundwater is often affected by the composition of the bedrock it passes through. Some bedrock components may be soluble in water and therefore affect its quality. In conjunction with a lithological summary, the drill cutting analysis from wells aid in determining zones within the subsurface containing relatively higher concentrations of naturally occurring arsenic. Drill cutting samples were collected from seven different wells located in Outagamie and Winnebago Counties (Table 1 and Figure 5). Trace metal analysis was only performed on four of these wells in an attempt to correlate areas of high arsenic concentrations with specific geologic strata. This data was used to confirm conclusions drawn from packer testing. Wells were chosen for drill cutting analysis based upon the availability of drill cuttings and location. The drill cuttings from the other three wells will be analyzed at a later date by the WDNR. The well construction reports and lithology reports for these three wells are on file at the WDNR.

Drill Cutting Collection and Analysis

Maple Leaf Dairy, Fox River Tractor, and Donald Valence

Drill cutting samples from the Maple Leaf Dairy well and the Fox River Tractor well were collected in the late 1940's or early 1950's either by the well driller or by the WGNHS and stored in the WGNHS repository. Samples were collected at five-foot intervals throughout the entire well. At the request of the WDNR, a portion of the drill cuttings were sent to WSLH for digestion and arsenic analysis. Drill cuttings from the Donald Valence well were collected by Schmidt's Well Drilling in cloth bags provided by WGNHS. The drill cuttings were forwarded to WSLH for digestion and arsenic analysis. The methods used by WSLH for digestion and arsenic analysis are in Appendix I. The remainder of the drill cutting samples are kept in storage at WGNHS for future use and analysis. A copy of the well construction report for each well is in Appendix IV.

Table 1. Summary of Drill Cutting Sample Locations and Well Information

Site Name	Location of Well		Total Depth (ft)
	County	Township	
Maple Leaf Dairy	Winnebago	Vinland	545
Fox River Tractor	Outagamie	Grand Chute	653
Donald Valence	Winnebago	Clayton	135
Dick Olson	Outagamie	Osborn	300
Drill Cuttings Collected But Not Analyzed			
Mark Bombinski	Winnebago	Neenah	101
Mike St. Louis	Outagamie	Greenville	161
W131-OU-416	Outagamie	Seymour	740

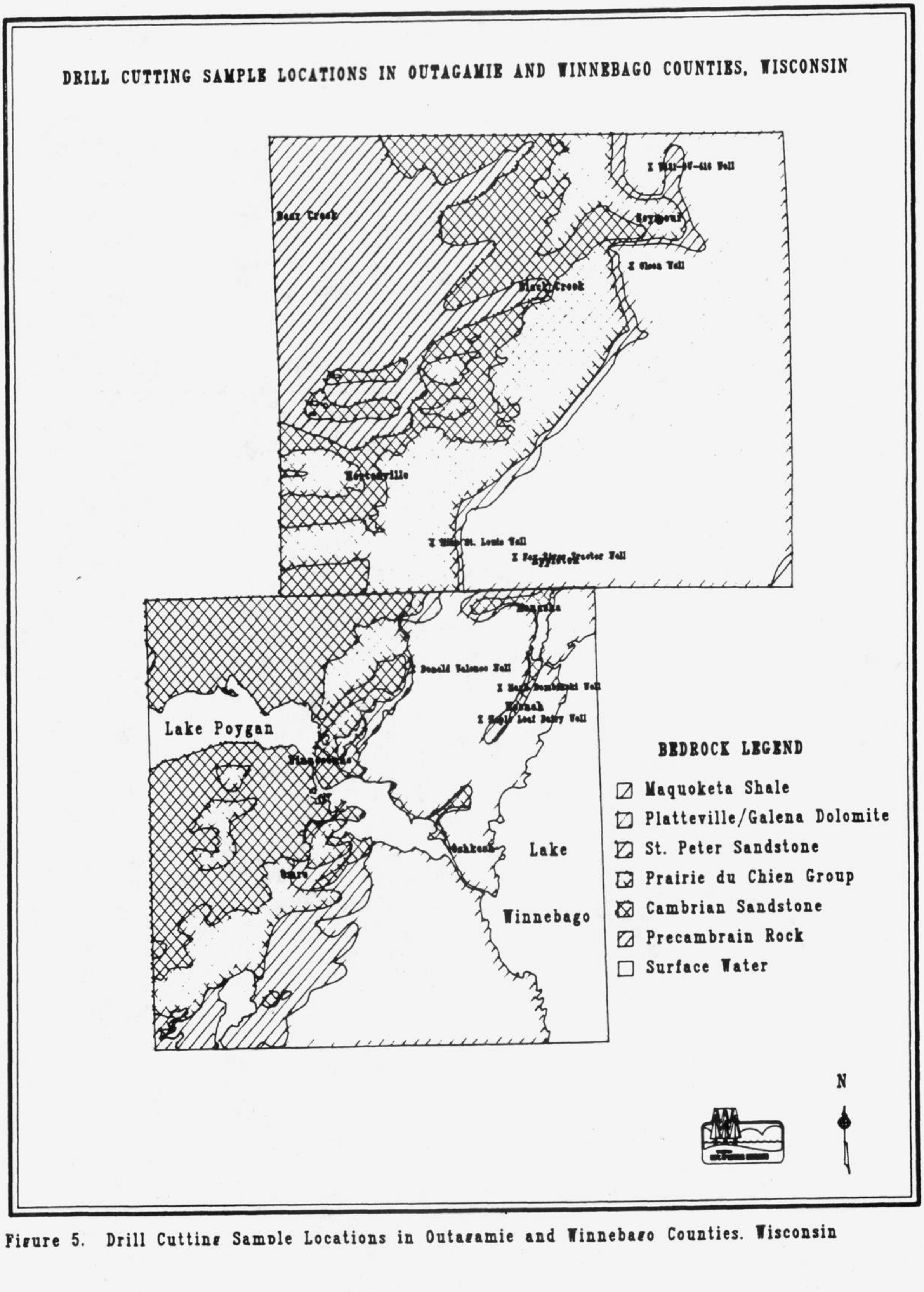


Figure 5. Drill Cutting Sample Locations in Outagamie and Winnebago Counties, Wisconsin

Drill Cutting Collection and Analysis

Dick Olson

Drill cuttings were collected at five-foot intervals throughout the newly constructed well column by the author. Drill cuttings from each five-foot interval were collected in a five gallon bucket and a representative subsample was taken. Drill cutting subsamples were stored in labeled cloth sample bags and allowed to dry. A portion of the sample was sent to the WSLH for digestion and arsenic analysis. The remaining portion was sent to WGNHS for lithological study and repository retainment. A copy of the lithology report is in Appendix IV. The methods used by the WSLH for the digestion and analysis of the drill cuttings are presented in Appendix I.

CHAPTER 4 - RESULTS and DISCUSSION

Private Well Arsenic Levels

Through the cooperative efforts of the WDNR, the Outagamie County Health Department and the Winnebago County Health Department, 1037 water samples from private wells located in Outagamie and Winnebago Counties were collected and analyzed for arsenic. The Outagamie and Winnebago County well locations and the arsenic concentrations found in them are shown in Plate 1 and Plate 2 respectively. Plate 1 indicates a general trend of elevated arsenic concentrations clustered within a five mile buffered strip surrounding the St. Peter Sandstone trend which extends to the northeast throughout Outagamie County. Most elevated arsenic concentrations in private water supplies in Outagamie County lie to the east of the mapped St. Peter Sandstone trend. This was anticipated because that is where the St. Peter Sandstone is presumably the aquifer supplying private wells. There are, however, areas where wells with elevated arsenic concentrations that lie west of the mapped St. Peter Sandstone trend. There should be no elevated arsenic levels west of the St. Peter Sandstone trend if it is the primary source of naturally occurring arsenic in the groundwater. However, high levels of arsenic west of the St. Peter Sandstone trend may be explained if the Prairie du Chien or the Cambrian sandstones also contribute arsenic to well water. This is reasonable because some drill cutting results and packer test results support this conclusion (discussed later in this chapter).

There is also a second feasible explanation for elevated arsenic in well water lying west of the erosional edge of St. Peter Sandstone. The map from which the bedrock contacts were taken indicates that in certain areas the St. Peter Sandstone subcrop is inferred because there was not enough data to map it accurately. Those areas of the St. Peter Sandstone subcrop that were inferred correspond to the areas where wells with elevated arsenic concentrations exist to the west of the mapped subcrop (Plate 1).

This suggests that the St. Peter Sandstone subcrop may be incorrectly mapped in certain areas.

The reasons for arsenic contamination west of the St. Peter Sandstone subcrop should be further studied to verify or discredit explanations given. It would be worthwhile, especially in those inferred areas, to more accurately map the location of St. Peter Sandstone subcrop. This would not only aid to further define the source of arsenic contamination in Outagamie and Winnebago Counties, but would also help well drillers reduce the likelihood of arsenic contamination when constructing new wells within the advisory area.

The geology of Winnebago County is more complex than that of Outagamie County and it is, therefore, more difficult to interpret the study results. Furthermore, Winnebago County had only one well that exceeded the health advisory for arsenic of 164 wells sampled in that county. A general trend from the plot of arsenic concentration and geology could not be easily determined. The only common feature was that wells with elevated levels of arsenic were found in areas where St. Peter Sandstone is present, based on existing bedrock geology maps.

The distribution of arsenic concentrations found in Outagamie and Winnebago Counties is found in Figure 6 and 7. These figures indicate that 37 of 1037 samples (3.6 %) exceeded the NR 140 Wisconsin Administrative Code of 50 μg/L As. This level is also the drinking water standard. When well water exceeded this level a health advisory was issued to the residents. Before issuing a health advisory, all wells that exceeded 50 μg/L As from the first water sampling were resampled and retested to confirm that the well water indeed did exceed the health advisory standard. The second sample was collected by the author and analyzed by the WSLH for arsenic to confirm the first result.

During the course of this study, the WSLH determined their limit of detection for arsenic to be 1 μg/L. Prior to December of 1992, the WSLH would only report

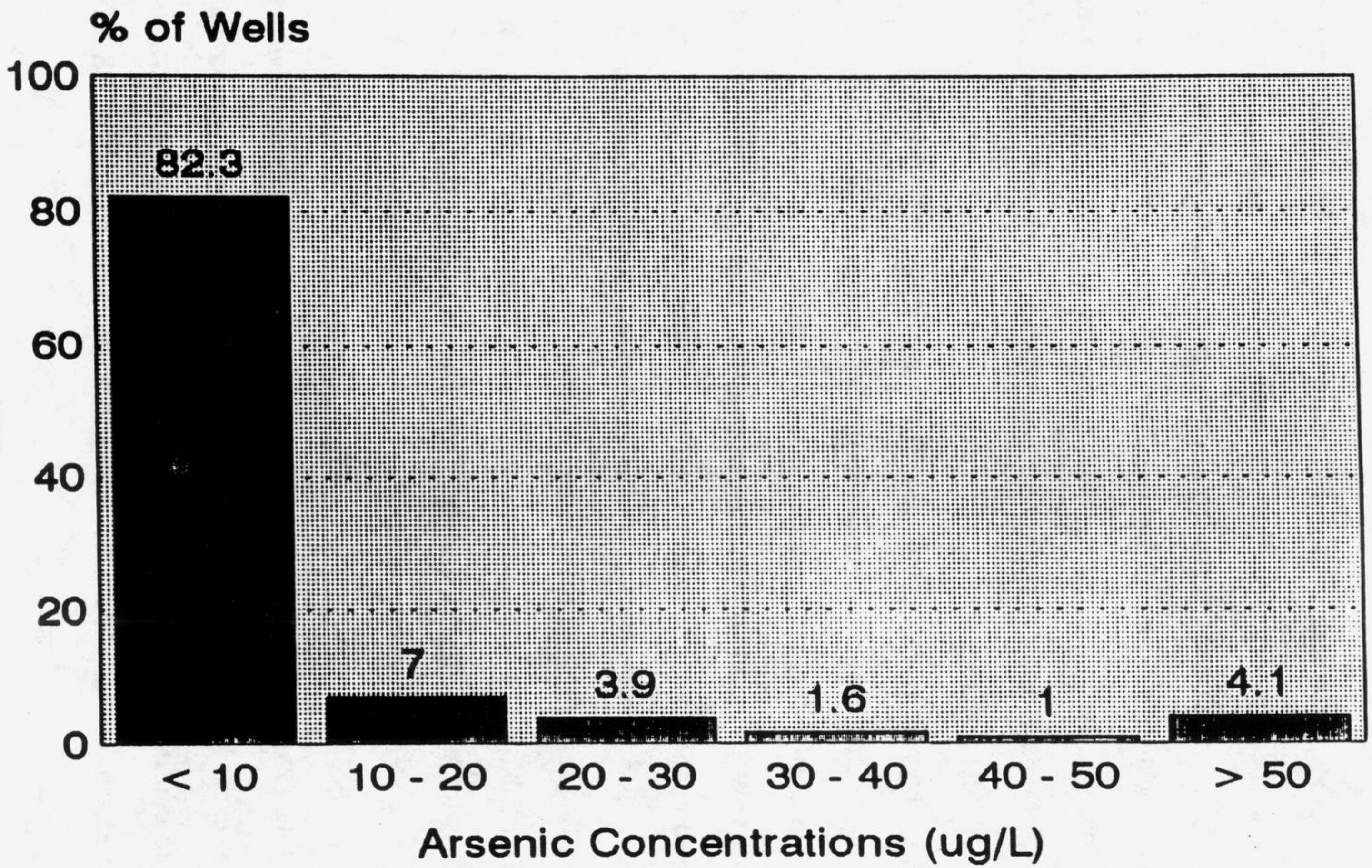


Figure 6. Distribution of Arsenic Levels Found in Private Water Supply Wells in Outagamie County, Wisconsin

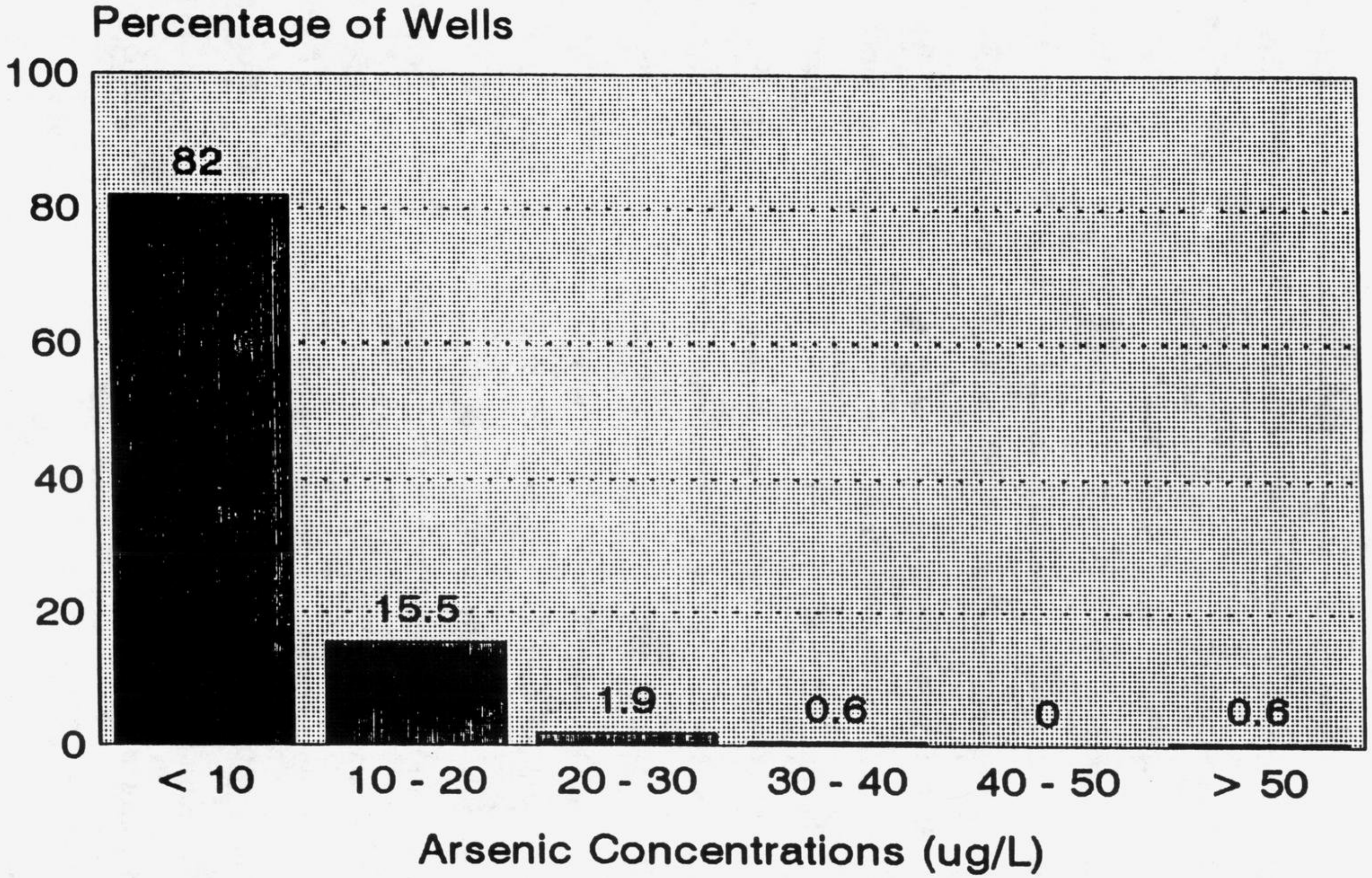


Figure 7. Distribution of Arsenic Concentrations in Private Water Supply Wells in Winnebago County, Wisconsin

arsenic concentrations of 10 μg/L or greater. Therefore, water samples analyzed prior to December of 1992, have arsenic concentrations that could only be reported from 10 μg/L or greater. At the request of the WDNR the WSLH recorded the raw value for any result below 10 μg/L. The raw value was only available for water samples analyzed after 1990. Thus, for water samples analyzed before 1990, a raw value lower than 10 μg/L was not obtainable. Thirty-nine well water samples were collected between 1990 and 1992. The arsenic raw data was available for all thirty-nine of these samples. Raw data was not available for thirty-four water samples collected before 1990. Thus, an arsenic result lower than 10 μg/L was not available.

An attempt was made to determine if a significant relationship exists between wells exceeding the arsenic health advisory and specific geologic strata. Construction reports of the wells sampled were consulted to determine the presence or absence of sandstone. Of the 1037 private wells sampled in Outagamie and Winnebago Counties, 491 well construction reports were found. Well construction reports are filled out by the well driller at the time of well construction. It reports the depth of the well, the casing depth, geologic strata encountered and other well information. Some well construction reports could not be located due to one of the following reasons: an error by the private home owner in locating their well on the map, little or no well information filled out by the homeowner on the well construction information questionnaire, inaccurate information filled out on the well construction information questionnaire, the well construction form was not filled out by the well driller, or the well driller recorded the wrong location on the well construction report. Since most well construction reports are filed by location, any misleading or wrong information about location of the well would prevent one from finding the well construction report.

Table 2. Chi-Square Summary to Determine Significance of Well Construction Report Information versus Arsenic Concentrations Exceeding Health Advisory

	As ≥ 50		As < 50		Totals
	Expected	Observed	Expected	Observed	
Sandstone *	15	11	227	231	242
No Sandstone *	15	19	234	230	249
Totals	30	30	461	461	491

* Lithology Recorded on the Well Construction Report

$\chi^2 = 2.3$ d.f. = 1

Table 2 shows the Chi-square table used to determine if a significant relationship exists between the presence As exceeding the drinking water standard (50 μg/L) and the presence of sandstone. The calculated χ^2 value for this data set is 2.3 with one degree of freedom. The critical value at 0.05 probability with one degree of freedom is 3.84. The calculated value is less than the critical value, therefore, no significant relationship exists between these two variables.

This effort to determine whether there was a significant relationship between the arsenic levels and geologic strata recorded in the well construction reports failed. An elevated arsenic concentration could not be correlated with a sandstone unit reported on the well construction report. Likewise, there was not a significant correlation between a limestone unit reported on the well construction report and an elevated arsenic level. Such a correlation may be possible from accurate well construction reports.

There are many problems, however, encountered when using well construction reports for information. Often the location of the well or ownership information is inaccurate or incomplete. This often results in misfiling of the report. WGNHS reports that greater than 10 percent of the reports submitted within the last few years have incorrect county, township, range and/or section information (WGNHS, 1991). Much information received about well construction, formation and /or pump test data is vague or inaccurate (WGNHS, 1991). Well drillers may feel that filling out well construction information is an added burden and that the information is of no valid use. Contrary to this notion, well construction reports are often consulted in any contamination problem or well problem. WDNR and other agencies use these reports (1) for site assessment problems e.g. siting a new landfill, (2) for evaluating potential contamination routes of a hazardous spill or leak, (3) for homeowners having problems with their well, and (4) for preparation of regional or statewide geologic and hydrogeologic maps (WGNHS, 1991). This information helps protect well users, groundwater and the environment. In this case, accurate reports could have further helped to discriminate the source of naturally occurring arsenic and thus been very important.

Spreeman Well - Water Quality Packer Test

The Spreeman well is located in Outagamie County, Greenville Township, NE1/4, NE1/4, Section 24, T21N, R16E. Leonard Spreeman was the original owner of the site; the original well was constructed by Malcolm Veitch on October 7, 1969. The original Spreeman well was 15.2 cm (6 in) in diameter and 36.6 m (120 ft) deep. According to the original well log, red clay was encountered to a depth of 8.5 m (28 ft) and is underlain by 1.2 m (4 ft) of hardpan. Gravel was encountered at 9.8 m (32 ft) below the surface with limestone (Platteville/Galena) encountered from 10.7 m to 25.9 m (35 to 85 ft). Sandstone (St. Peter) was documented from 25.9 m to 36.6 m (85 to 120 ft). The well was cased to 15.2 m (50 ft) with black steel casing grouted in place with cement to a depth of 15.2 m (50 ft). The original Spreeman well construction report is shown in Appendix IV. On June 19, 1990, the well was reconstructed to the depth of 97.8 m (321 ft) by Bill Van De Yacht. It should be noted that the required well reconstruction form was not filed by the well driller thus, no subsurface information about the well was available beyond 36.6 m (120 ft).

The Spreeman well was one of two private wells selected for more intensive investigation because of elevated As and Fe levels. On January 29, 1993, a second water sample from the Spreeman well was collected. The water was sent to the WSLH and analyzed for arsenic, iron, calcium, chloride, conductivity, pH, alkalinity, hardness, magnesium, sodium, sulfate and total solids. In the field the WDNR measured field pH and temperature. The results of these analysis are found in Table 3.

The analytical results for the January 29, 1993, sample indicates that the well had an unusually low pH of 4.3 by a field measurement and 3.8 by a lab measurement. The normal pH range for groundwater is between 6 and 8. A pH of 4.3 is very acidic for well water and is likely a contributing factor for the increased arsenic and iron concentration in the well water. Acidic water can corrode a plumbing system, oxidizing metals associated with pipes into soluble forms and thus into the water supply. Acidic water also will generally increase the solubility of some minerals within an aquifer thus incorporating metal ions into the water supply.

Layne-Northwest was contracted to perform the packer test, caliper log, and gamma-ray log on the Spreeman well because the well had no subsurface information available below 36.6 m (120 ft). The packer test was used to determine specific zones within the Platteville/Galena, St. Peter Sandstone, and Prairie du Chien formations that would yield adequate water quality and quantity for potable use. The consultant provided the necessary equipment to perform the packer, caliper, and gamma-ray testing and also, ensured the well was returned to its original state once tests were completed.

Table 3. Results of the Second Sampling of Spreeman Well Water on January 29, 1993

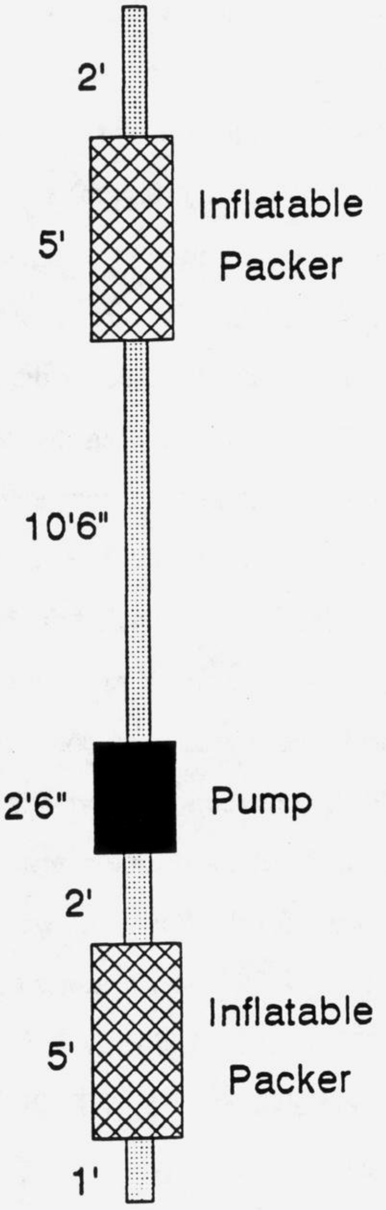
Parameter	Concentration (mg/L) unless noted	Drinking Water Standards (mg/L)
Arsenic	360 μg/L	50 μg/L
Calcium	100	Not Applicable
Chloride	< 1	250
Conductivity	1700 umhos/cm	Not Applicable
pH, Lab	3.80 SU	Not Applicable
Alkalinity	****	Not Applicable
Hardness	530	Not Applicable
Iron	250	0.3
Magnesium	67	Not Applicable
Sodium	8.0	Not Applicable
Sulfate	1000	250
Total Solids	1830	Not Applicable
Field Temperature	12.6 C	Not Applicable
Field pH	4.3 SU	Not Applicable

The packer interval selected by the WDNR for pumping was 4.6 m (15 ft). Selection of the interval between the two inflatable packers and the depth settings of the packers within the well column were based on the original well construction report and the gamma-ray log. A diagram of the Spreeman packer assembly used by Layne-Northwest is shown in Figure 8. Each interval was pumped for approximately 10 minutes at 37.8 L/min (10 gpm) so that a representative water sample could be obtained from each formation.

The packer test intervals were chosen to define variations in arsenic concentration within the well column and to cover the entire well column with the fewest number of packer tests. The contact between the Platteville/Galena and the St. Peter Sandstone formations, the zone thought to contribute relatively high arsenic concentrations to the water, could not be packed off to obtain a water sample because of undocumented well reconstruction which extended the casing to 27.4 m (90 ft). The existence of the casing extension was unknown prior to choosing the well for the packer test. The casing extension was found upon completion of the caliper log. The casings length in the original well construction report was given as 15.2 m (50 ft), roughly 9.1 m (30 ft) above the St. Peter Sandstone contact.

Packer testing for the Spreeman well began on February 3 and continued through February 5, 1993. The water samples collected between each packer interval were sent to the WSLH for analysis of arsenic, iron, cadmium, copper, manganese, and zinc. They were also tested by WDNR for field pH. The results of the packer test analysis are shown in Table 4.

The results from the packer test indicated that the arsenic concentration found throughout the entire well column remained above the health advisory level of 50 μg/L. The arsenic concentration was the highest at the contact between the Prairie du Chien and the Cambrian sandstones (83.2 m to 87.8 m) (273 ft to 288 ft) (Figure 9). However, this concentration may have resulted from the excessive sediment found in



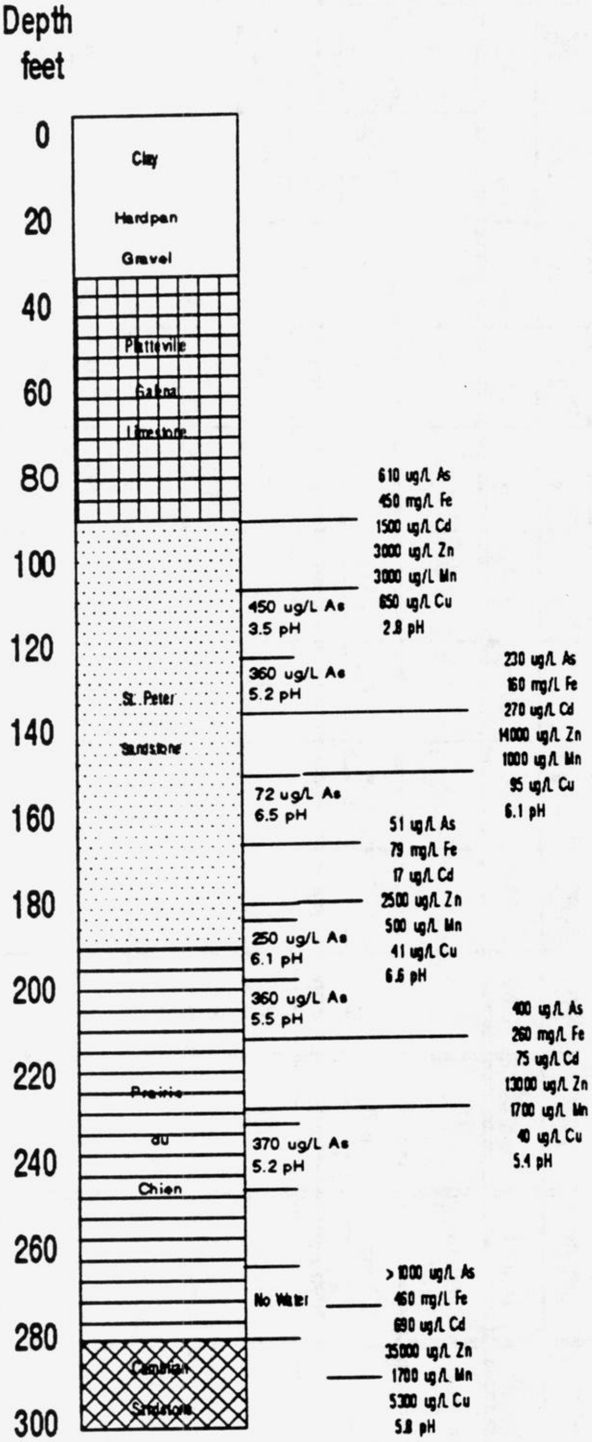
Total Length 28 feet

Figure 8. Diagram of the Packer Assembly used in the Spreeman Well Packer Test

Table 7. Summary of Olson Packer Test Results from March 17 to March 23, 1993

Parameters	Health Standards	Units Reported In	Packer Intervals [Identification (top) and Depth within well column in feet (below)]									
			P4	P1	P1A	P2	P3	No Water	P5	P6	P7	P8
			41-110	41-144	114-144	144-174	174-204	204-234	234-264	264-284	264-300	131-300
As	50 µg/L	µg/L	220	51.1	49.0	9.6	7.7	NA	23	24	24	220
Cd	10 µg/L	µg/L	0.60	NA	0.30	0.06	0.04	NA	1.2	0.66	0.68	8.2
Parameter	**Welfare Standards**											
Fe	0.3 mg/L	mg/L	13.0	4.11	3.68	0.681	0.823	NA	1.9	1.7	1.8	15
Cu	1000 µg/L	µg/L	<20	NA	<20	<20	<20	NA	100	<20	<20	<20
Mn	50 µg/L	µg/L	100	NA	<40	<40	<40	NA	<40	<40	<40	140
Zn	5000 µg/L	µg/L	860	NA	590	210	210	NA	2900	510	470	4900
Field Parameters												
Field pH		SU	7.07	7.13	7.10	7.20	7.08	NA	6.51	6.77	7.20	NA
Field Temp		Degrees Celcius	7.2	[1]	6.2	6.9	7.9	NA	8.4	9.0	8.9	NA

NA - Not Applicable - the water sample was not tested for that parameter.
SU - Standard Units
[1] - Equipment problem
Conversion from feet to meters 1 ft = 0.3 m



HEALTH STANDARDS

50 ug/L As
10 ug/L Cd

WELFARE STANDARDS

0.3 mg/L Fe
50 ug/L Mn
5000 ug/L Zn
1300 ug/L Cu

KEY

As = Arsenic
Cd = Cadmium
Cu = Copper
Fe = Iron
Mn = Manganese
Zn = Zinc

ug/L = micrograms per liter
mg/L = milligrams per liter

Figure 9. Graphical Depiction of Spreeman Packer Test Results.

this zone. The bottom 6.1 m (20 ft) of the well was filled in with sediment. During the packer test, sediment probably from the bottom of the well column, was drawn up through the pump and into the sample. Because head monitoring was not possible below the bottom packer, the bottom packer may have had a faulty seal resulting in sediment being incorporated into the sample. In fact, sediment clogged the pump during the packer test and stopped it. Elsewhere, arsenic concentrations were highest in the upper portions of the St. Peter Sandstone (610 μg/L). Arsenic concentrations declined to 51 μg/L at the bottom of the St. Peter Sandstone. This trend correlates with the findings from drill cutting analysis (described later) which also showed a marked increase in arsenic concentrations in the upper portions of the St. Peter Sandstone compared to levels in the bottom of the St. Peter Sandstone. The packer test results show the arsenic concentration increasing in the Prairie du Chien dolomite (55.8 m to 75.6 m) (183 ft to 248 ft). This trend was somewhat puzzling because it does not correlate with other analytical results for As from drill cuttings. Drill cutting analysis of the Prairie du Chien dolomite suggests that it has low concentrations of arsenic within it.

High arsenic concentrations appear to correlate with low field pH values. Also, other high metal concentrations (Cd, Fe, Mn, Cu, and Zn), even though not determined on all samples, seem to correlate with the arsenic levels observed. It appears that as the pH decreases the metal ion concentrations in the groundwater increase. Low pH values promote soluble metal ions perhaps by dissolving metallic minerals in the aquifer.

Iron concentrations found in the packer test intervals exceeded the standard for iron of 0.3 mg/L. Iron concentrations exceeding the standard typically cause aesthetic nuisance problems such as odor and staining. In addition, cadmium levels exceeded the health advisory of 10 μg/L in all of the packer intervals analyzed for cadmium. Copper concentrations exceeded the health advisory of 1300 μg/L in only one of the packer test intervals. This interval was the bottom one which contained large amounts of sediment in the sample. Manganese concentrations remained over the advisory of 50 μg/L in all of the packer intervals selected to be analyzed. Zinc concentrations exceeded the advisory of 5000 μg/L in all but one of the packer intervals tested. The low pH may also provide an answer as to why there is excessive amounts of these metals present in the water supply.

Due to the abnormally low pH found in the Spreeman well, it deserves more attention. Neighboring wells surrounding the Spreeman well were sampled and analyzed for pH, however, nothing unusual was found. Two wells in Outagamie County (Porter well and Schneider well) are also known to have or to have had low pH in their well water. The Porter well located in Outagamie County, Oneida Township, SE1/4, SE1/4, Section 10, T23N, R18E, has an abnormally low pH of 2.5. The WDNR is presently studying the Porter well further to determine whether this pH is of natural or human origin. Neighboring wells surrounding the Porter well were also sampled and analyzed for pH, however, nothing abnormal was reported. The Schneider's original well was located within one mile of the Spreeman well located in Outagamie County, Greenville Township, E1/2, NW1/4, Section 14, T21N, R16E, and was found to also have a low pH of 3.0 in 1967. The wells of the Schneider's neighbors were sampled and analyzed for pH in 1967, however, nothing unusual was reported. A human source for the low pH problems at the Schneider well could not be located. The Schneiders elected to have another well drilled on their property to alleviate the pH problem. The pH from their new well was reported to be normal.

The Spreeman packer test results showed that the pH in the well varied throughout the well column. This suggested that the source of the low pH may be within a specific formation (specifically, the St. Peter Sandstone). Water from the upper portion of the St. Peter Sandstone was found to contain substantially lower pH than that of lower portions of the well. Groundwater associated with low pH may contain free-mineral acid from mine water, volcanic gases or contaminants by man-made sources (Driscoll, 1986). It is highly unlikely that the acid in the Spreeman well is due to volcanic gases. Thus, it may be more likely that the acidic nature of the Spreeman well water is derived from minerals within the St. Peter Sandstone that have oxidized forming sulfuric acid or it may be derived from a man-made source. However, due to the presence of other wells known to have low pH's, and the Spreeman packer test results which shows dramatic changes in well water pH with depth, man-made sources are unlikely. Only a few natural reactions are known to cause low pH. Driscoll (1986) mentions that the acids from mine waters tend to derive from the oxidation of iron pyrite or other metal sulfide minerals to form sulfuric acid. The chemical reaction sequences occurring in acids from mine waters causing pH values as low as 2 taken Manahan, 1991 are:

Oxidation of Sulfide in Pyrite Occurring in the Presence of Water

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

Oxidation of Ferrous Ion to Ferric Ion

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

Ferric Ion Further Dissolves Pyrite

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

2 + 14 → 15 F

The initial oxidation of sulfide in pyrite requires oxygen and is slow. Once this oxidation is initiated releasing ferrous iron and sulfate the reaction may be catalyzed by iron-oxidizing bacteria even at very low oxygen concentrations. The iron bacterium *Thiobacillus ferrooxidans* may catalyze the reaction below pH of 3.5 (Manahan, 1991). Within the pH range of 3.5 and 4.5 the reactions may be catalyzed by filamentous iron bacterium (*Metallogenium*) (Manahan, 1991). Other bacteria that may participate in these catalyzing these chemical reactions are *Thiobacillus thiooxidans* and *Ferrobacillus ferrooxidans* (Manahan, 1991).

Pyrite is known to exist at least in trace quantities within the Platteville/Galena Dolomite and St.Peter Sandstone from drill cutting lithology reports (Donald Valence lithology report Appendix IV). Oxidation of these trace quantities of pyrite may contribute to the acidic nature of the groundwater. Oxidation of pyrite, also, may cause elevated levels of arsenic in groundwater because arsenic tends to be associated with sulfide minerals with pyrite as one of its principal carriers. Also, pyrite within lenses existing in the subsurface near or within the St. Peter Sandstone may exist in larger quantities than mentioned in a lithology report. It may not be possible to discern where or if these lenses of pyrite exist because of the way in which drill cutting samples are collected. Drill cutting samples represent only a small portion from a five-foot zone within a well column. Drill cutting samples are often grab samples taken at anytime during the drilling of a five-foot interval. Thus, it is not a true representation of the entire five-foot interval even though it may be represented as such in a lithological report. In fact, larger lenses of the pyrite may exist within the upper St. Peter Sandstone because pyrite is known to exist in other wells with trace quantities of pyrite that have no pH problems. This is supported by preliminary investigations surrounding the Porter well (described earlier). Corings from the contact between the Platteville/Galena and the St. Peter Sandstone were obtained. Pyrite or a pyrite-like mineral was visually observed when inspecting the corings. Also, the lithology of the Spreeman well is undefined because no drill cutting samples were collected.

A point that should be made is that these chemical reactions are mediated and often catalyzed by certain microorganisms mentioned previously. The chemical reaction sequence given earlier requires the presence of oxygen. Oxygen may be provided to the iron-rich water flowing from the aquifer by frequent pumping or may be provided at the well/rock interface where oxygen may be present (Smith and Tuovinen, 1985).

Other interesting chemical reactions that may take place when soluble iron (II) or manganese (II) is present in groundwater is that insoluble iron (III) and manganese (IV) form (Manahan, 1991). The chemical reactions from Manahan are given below:

$4Fe^{2+}(aq) + O_2(aq) + 10H_2O \text{ ---> } 4Fe(OH)_3(s) + 8H^+$

$2Mn^{2+}(aq) + O_2(aq) (2x+2)H_2O \text{ ---> } 2MnO_2.xH_2O(s) + 4H^+$

These insoluble precipitates of iron (III) and manganese (IV) may form an impermeable layer coating surfaces where water flows into a well (Manahan, 1991). These precipitates fill in pore spaces that water would use to enter a well (Manahan, 1991). This type of coating may be forming within the Spreeman well impeding water flow into the well. Thus, the well may be drawing more water from reduced acidic zones versus plugged acidic zones.

The cation and anion concentrations within well water can be used to determine the general quality of the groundwater. Common cations usually present in groundwater are Ca^{2+}, Mg^{2+}, Na^+, and Fe^{2+}. Common anions present in groundwater are HCO_3^-, SO_4^{-2}, and Cl^-. The cation and anion concentrations should be equal. Table 5 shows the cations and anions present in both the Spreeman and Porter wells.

The cations and anions totals should be equivalent. In both cases they are not. One contributing factor to the error is that the method for analysis of sulfate lack precision. In both wells there are significant amounts of sulfate present. A second contributing factor to the cation-anion imbalance is the fact that not all possible cations were determined. For example, these samples likely contain significant

Table 5. Cation and Anion Comparison for the Spreeman and Porter Wells

Cations (meq/L)	Spreeman Well 01/29/93	Porter Well 11/16/92 Sample Depth 60 ft
Ca^{2+}	5.0	2.65
Mg^{2+}	2.76	2.88
Na^+	8.96	.52
Fe^{2+}	0.35	29.75
Total	17.07	35.80
Anions (meq/L)		
HCO_3^-	None Present Due to pH	None Present Due to pH
SO_4^{-2}	20.8	58.3
Cl^-	<0.1	<0.1
Total	20.8	58.3

amounts of Mn (II), Zn (II), and Pb (II) and possibly other metal ions. These were not measured.

The presence of high concentrations of iron and sulfate suggest that the acidic nature of both wells may have been derived from a natural source, possibly, the oxidation of pyrite. Groundwater that contains high dissolved iron concentrations often can be related to the oxidation of reduced iron minerals (Smith and Tuovinen, 1985).

Highly acidic environments in aquifers are rare with exception of those environments contaminated with acid mine drainage or acidophilic bacteria. Both acid mine drainage and acidophilic bacteria usually do not occur in water wells (Smith and Tuovinen, 1985). Therefore, not much is known about the bacterial catalyzed oxidation of iron in groundwater and water wells (Smith and Tuovinen, 1985). Wells with pH values as low as the Spreeman, Porter and Schneider wells are rare. The origin of the acidic nature of well water needs further study.

Olson Well - Water Quality Packer Test

The second packer test was performed from March 17 through March 24, 1993, on the Olson well located in Outagamie County, Osborn Township, NW1/4, NW1/4, Section 8, T23N, R18E. Dick and Sue Olson were the original owners of the well constructed by Bill Van De Yacht on November 14, 1984. The original well borehole was 22.9 cm (9 in) in diameter from the surface to 12.5 m (41 ft), and then was drilled 15.2 cm (6 in) in diameter from 12.5 m (41 ft) to a total well depth of 30.8 m (101 ft). According to the original well log, clay was encountered to a depth of 2.7 m (9 feet). The clay was underlain by 12.5 m (41 ft) of limestone (Platteville/Galena). Sandstone (St. Peter) was encountered at 15.2 m (50 ft) below the surface, extending throughout the rest of the well column to the total depth of 30.8 m (101 ft). The well was originally cased to 12.8 m (42 ft) with black steel casing grouted in place. The original Olson well construction report is shown in Appendix IV. On March 15, 1993, the well was reconstructed to the depth of 91.4 m (300 ft). Drill cuttings from the reconstruction of the well were obtained by a WDNR representative. The Cambrian sandstone was encountered at 70.1 m (230 ft); the overlying Prairie du Chien was absent.

The Olson well was first sampled on December 18, 1992, due to a complaint of iron problems from the owners of the well. The author sampled the well for both iron and arsenic because the well was located near the St. Peter Sandstone trend. Initial test results revealed an arsenic concentration of 1200 μg/L, the highest arsenic concentration recorded in a private water supply well in Outagamie County. The iron concentration was also high (87 mg/L). On February 18, 1993, the author collected a second water sample from the well and sent it for analysis of arsenic, cadmium, chloride, chromium, conductivity, pH, alkalinity, barium, calcium, copper, iron, magnesium, sodium. zinc, hardness, lead, nitrate+nitrite-nitrogen, selenium, silver, sulfate, total solids, field pH, and field temperature. The results of the second sample are shown in Table 6. Both the field pH and lab pH indicated normal ranges for groundwater. The levels of the other metals present in the water supply are abnormally high for well water.

The results from this sampling indicated that arsenic and cadmium exceeded the drinking water health standards and iron, manganese, zinc, and sulfate exceeded the welfare standards set by the EPA. Furthermore, these results indicate the need to analyze the packer test samples not only for arsenic but for cadmium, iron, manganese, zinc and sulfate to further delineate the zones of poor water quality.

Luisier Well Drilling was contracted to perform the packer test on the Olson well. The packer test was used to determine specific zones within the Platteville/Galena, St. Peter Sandstone, and the Cambrian sandstones that would yield adequate water quality and quantity for potable use. The consultant provided the necessary equipment to

Table 6. Results of the Second Sampling from Olson Well Water taken February 18, 1993

Parameter	Results	Standard	Parameter	Result	Standard
Conductivity (25 Deg C), Dissolved	739 umhos/cm	NA	Conductivity (25 Deg C)	743 umhos/cm	NA
pH, Lab, Dissolved	7.02 SU	NA	pH, Lab	6.17	NA
Alkalinity, Dissolved	48 mg/L	NA	Alkalinity	60 mg/L	NA
Arsenic	720 μg/L	50 μg/L *	Sodium	2.4 mg/L	NA
Cadmium	53 μg/L	10 μg/L *	Zinc	20000 μg/L	5000 μg/L
Chloride	4.0 mg/L	250 mg/L	Hardness	350 mg/L	NA
Chromium	8.2 μg/L	50 μg/L	Lead	12 μg/L	50 μg/L
Barium	< 40 μg/L	1000 μg/L	Nitrate + Nitrite-N	< 1.00	10 mg/L
Calcium	87 mg/L	NA	Selenium	ND	10 μg/L
Copper	390 μg/L	1300 μg/L	Silver	ND	50 μg/L
Iron	80 mg/L	.3 mg/L	Sulfate	330 mg/L	250 mg/L
Magnesium	33 mg/L	NA	Total Solids	746 mg/L	NA
Manganese	490 μg/L	50 μg/L	Field Temperature	8.5 C	NA
Sodium	2.4 mg/L	NA	Field pH	6.33 SU	NA

NA = Not Applicable
Note: All water samples analyzed by SLOH

perform the packer test and ensured the well was returned to a bacteriologically safe condition once the tests were completed.

The packer test interval selected by the WDNR for pumping was 9.1 m (30 ft). Selection of the interval between the two inflatable packers and the depth settings of the packers within the well column were based on the original well construction report, the drill cuttings collected, and the packer assembly. A diagram of the packer assembly used in the Olson well is shown in Figure 10. Each interval was pumped for approximately 10 minutes at 37.8 L/min (10 gpm) so that a representative water sample could be obtained from each interval.

The packer test intervals were chosen to define variations in arsenic concentration within the well column and to cover the entire well column with the fewest number of samples. The contact between the Platteville/Galena Formation and the St. Peter Sandstone, the interval thought to contribute relatively high arsenic concentrations to the well water, could not be packed off to obtain a water sample because of the packer assembly design used by Layne-Northwest.

The results from the water samples collected from the packer test intervals at the Olson well between March 17 through March 24, 1993, are found in Table 7. The analytical results of the packer test show a general decline in arsenic concentrations with depth within the well column. All of the water samples collected from the packer test intervals indicate a significant reduction in arsenic concentration from that of the original shallower well. Two water samples from the original well had arsenic concentrations of 1200 μg/L and 720 μg/L. The upper portion of the St. Peter Sandstone [34.7 m to 43.9 m (114 ft to 144 ft)] exhibits higher arsenic concentrations than those found in the base of the St. Peter Sandstone [43.9 m to 62.2 m (144 ft to 204 ft)] and in the Cambrian sandstones [71.3 m to 91.4 m (234 ft to 300 ft)] found below it (Figure 11). Arsenic concentrations within the water increase in the

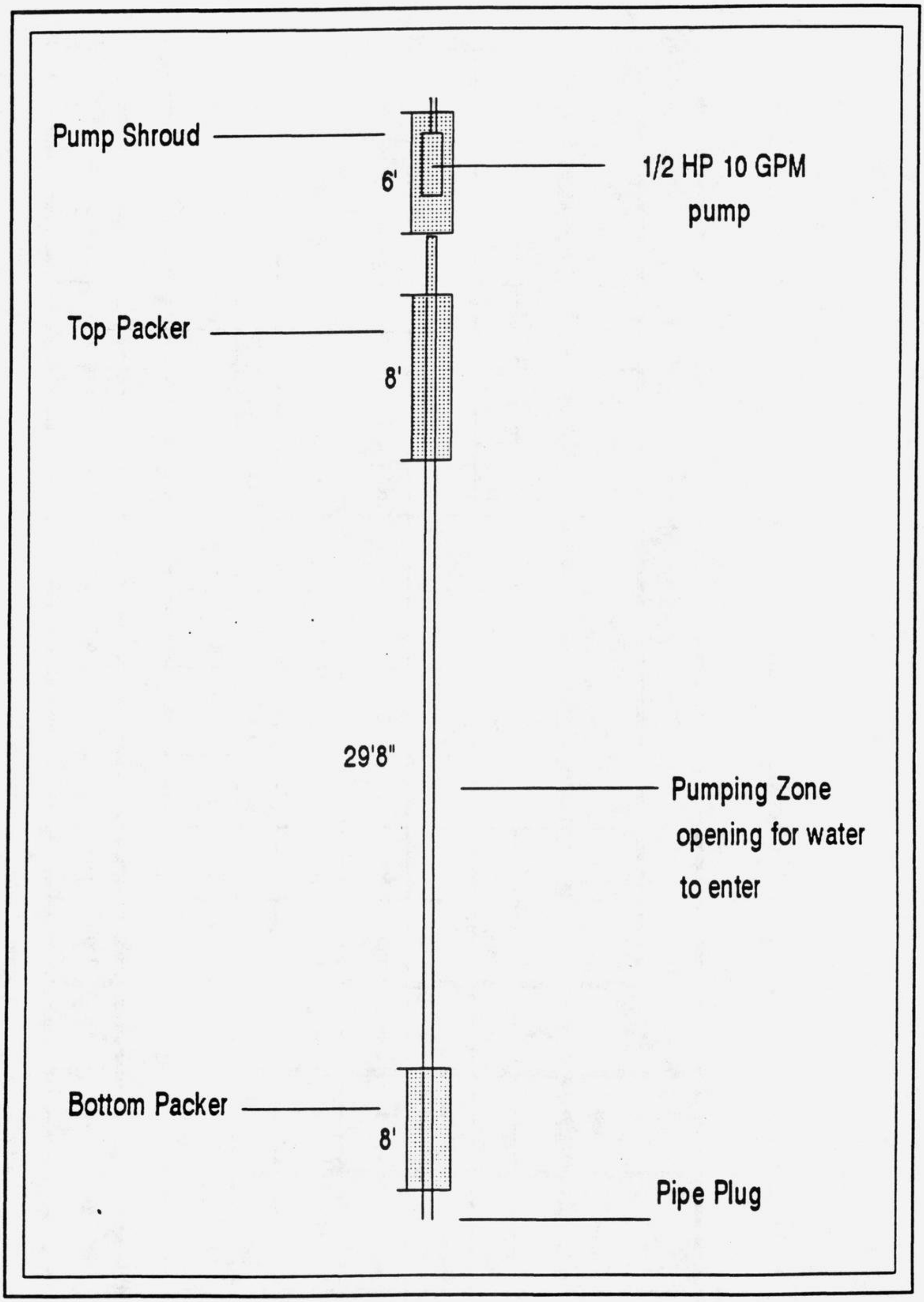
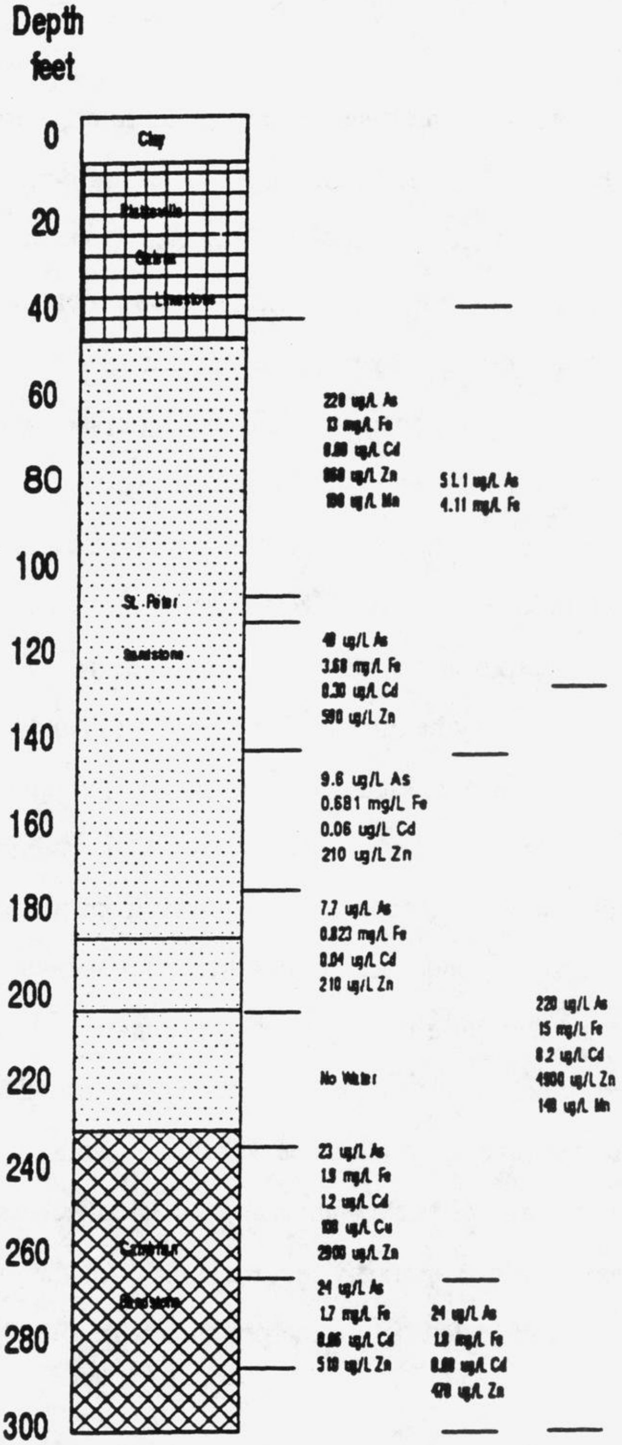


Figure 10.- Diagram of the Packer Assembly used in the Olson Well Packer Test

Table 4. Summary of Spreeman Packer Test Results from February 1993

Parameter	Health Stnd.	Units	Packer Interval (feet)											
			90-105	105-120	120-135	135-150	150-165	165-180	183-198	198-213	213-228	233-248	265-280	273-288
As	50 µg/L	µg/L	610	450	360	230	72	51	250	360	400	370	NW	>1000
Cd	10 µg/L	µg/L	1500	NA	NA	270	NA	17	NA	NA	75	NA	NW	690
Parameter	Welfare Stnd.													
Fe	0.3 mg/L	mg/L	450	NA	NA	160	NA	79	NA	NA	260	NA	NW	460
Cu	1000 µg/L	µg/L	650	NA	NA	95	NA	41	NA	NA	40	NA	NW	5300
Mn	50 µg/L	µg/L	3000	NA	NA	1000	NA	500	NA	NA	1700	NA	NW	1700
Zn	5000 µg/L	µg/L	24000	NA	NA	14000	NA	2500	NA	NA	13000	NA	NW	35000
Field Parameter														
Field pH		SU	2.80	3.49	5.15	6.10	6.47	6.58	6.10	5.48	5.36	5.24	NW	5.76

Note: All packer test water samples were filtered before analysis



HEALTH STANDARDS
50 ug/L As
10 ug/L Cd

WELFARE STANDARDS
0.3 mg/L Fe
50 ug/L Mn
5000 ug/L Zn
1300 ug/L Cu

KEY
As = Arsenic
Cd = Cadmium
Cu = Copper
Fe = Iron
Mn = Manganese
Zn = Zinc

ug/L = parts per billion
mg/L = parts per million

Figure 11. Graphical Depiction of Olson Packer Test Results.

Cambrian sandstones, however, they remain below the current health standard (50 μg/L).

Iron concentrations follow the same trend as the arsenic trend, with higher concentrations noted in the upper St. Peter Sandstone. The iron concentration in the well water declines in the lower portion of the St. Peter Sandstone and then rises somewhat within the Cambrian sandstones. The iron concentration in the well water received from the packer test remains above the welfare standard throughout the entire well column, however, the iron concentrations are significantly reduced from that of the original well which had a iron concentration of 80 mg/L.

The data received from packer interval P8 (Table 7) are somewhat puzzling because the arsenic concentration exceeds the average arsenic concentration from well water obtained within the same portions of the well column during the packer tests. The high arsenic concentrations may be attributed to a leaking packer set at 39.9 m (131 ft). This would allow the arsenic contaminated water in the upper portion of the well to drain into the lower portion causing an abnormally high arsenic concentration and thus the sample would not represent the water received from that portion of the well column. The higher arsenic concentration may be also associated with contamination of arsenic and iron built up in the pressure tank or may be due to a torn pressure tank bladder which would allow for outside contamination. This is plausible because the water sample for packer interval P8 was collected after the pressure tank. The water sample for packer interval P8 was collected after the pressure tank because the Olson's temporarily required water for bathing purposes. All other water samples were collected before the pressure tank directly from the packer assembly pump.

The above results suggest that water received from 48.8 m (160 ft) or lower may significantly reduce the arsenic and iron concentration within the Olson well. The results indicate that extending the casing of the new well to at least 48.8 m (160 ft) should improve water quality.

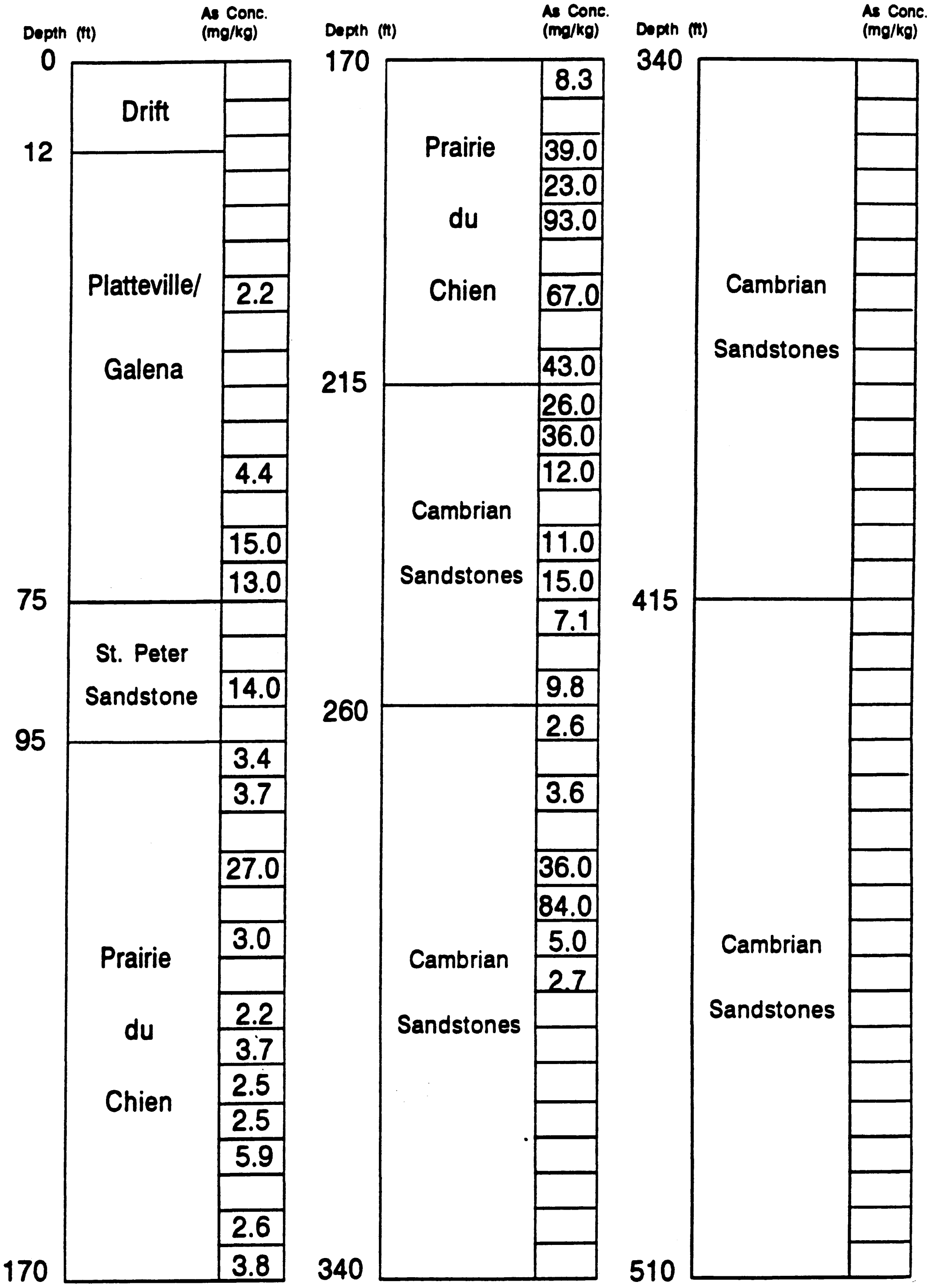
Drill Cutting Results

Maple Leaf Dairy Well

The Maple Leaf Dairy well, located in Winnebago County, Vinland Township, NE1/4, NE1/4, Section 1, T19N, R16E was one of the wells chosen for analysis of arsenic in drill cuttings. These drill cuttings were analyzed both to provide a basis for background concentrations of arsenic in bedrock formations in the county and to distinguish where higher concentrations of arsenic exist within a vertical geologic profile. The drill cutting samples were received from the repository of the WGNHS and shipped directly to the WSLH for digestion and arsenic analysis.

The well was constructed in 1946 by I. E. Brown. Drill cutting samples were examined by F. T. Thwaites to determine lithology and formations. The Maple Leaf Dairy well is 20.3 cm (8 in) in diameter and 166.1 m (545 ft) deep. According to the well log, clay and gravel was encountered to a depth of 3.7 m (12 ft) underlain by 19.2 m (63 ft) of Platteville/Galena Dolomite. The St. Peter Sandstone was encountered at a depth of 22.9 m (75 ft) and underlain by 36.6 m (120 ft) of Prairie du Chien Dolomite, encountered at 29.0 m (95 ft). The Cambrian Sandstones were found from 65.5 m (215 ft) to the well bottom. The Trempealeau Sandstone was found at 65.5 m (215 ft) to a depth of 79.2 m (260 ft). Franconia Sandstone was encountered below the Trempealeau to a depth of 126.5 m (415 ft). The Dresbach Sandstone was encountered beneath this from 126.5 m (415 ft) to the bottom of the well. The well is cased and grouted in place with cement to a depth of 30.5 m (100 ft). The Maple Leaf Dairy well log and lithology report is shown in Appendix IV.

Thirty-five drill cutting samples from the Maple Leaf Dairy well were analyzed for arsenic. The results are shown in Figure 12. The results indicated a



Note: Blank Squares represent interval not analyzed

Figure 12. Drill Cutting Results for Maple Leaf Dairy Well

relatively higher arsenic concentration within the St. Peter Sandstone relative to the Platteville/Galena Dolomite. The Prairie du Chien Dolomite, however, had higher arsenic concentrations within zones of the formation composed of sandstone versus zones composed of dolomite. The Cambrian sandstones contained relatively higher levels of arsenic than those found in dolomitic parts of the Prairie du Chien and Platteville/Galena Formation. The Cambrian sandstone arsenic concentrations, however, were lower than those found in the sandy facies of the Prairie du Chien, thus, the Prairie du Chien may also contribute arsenic to groundwater.

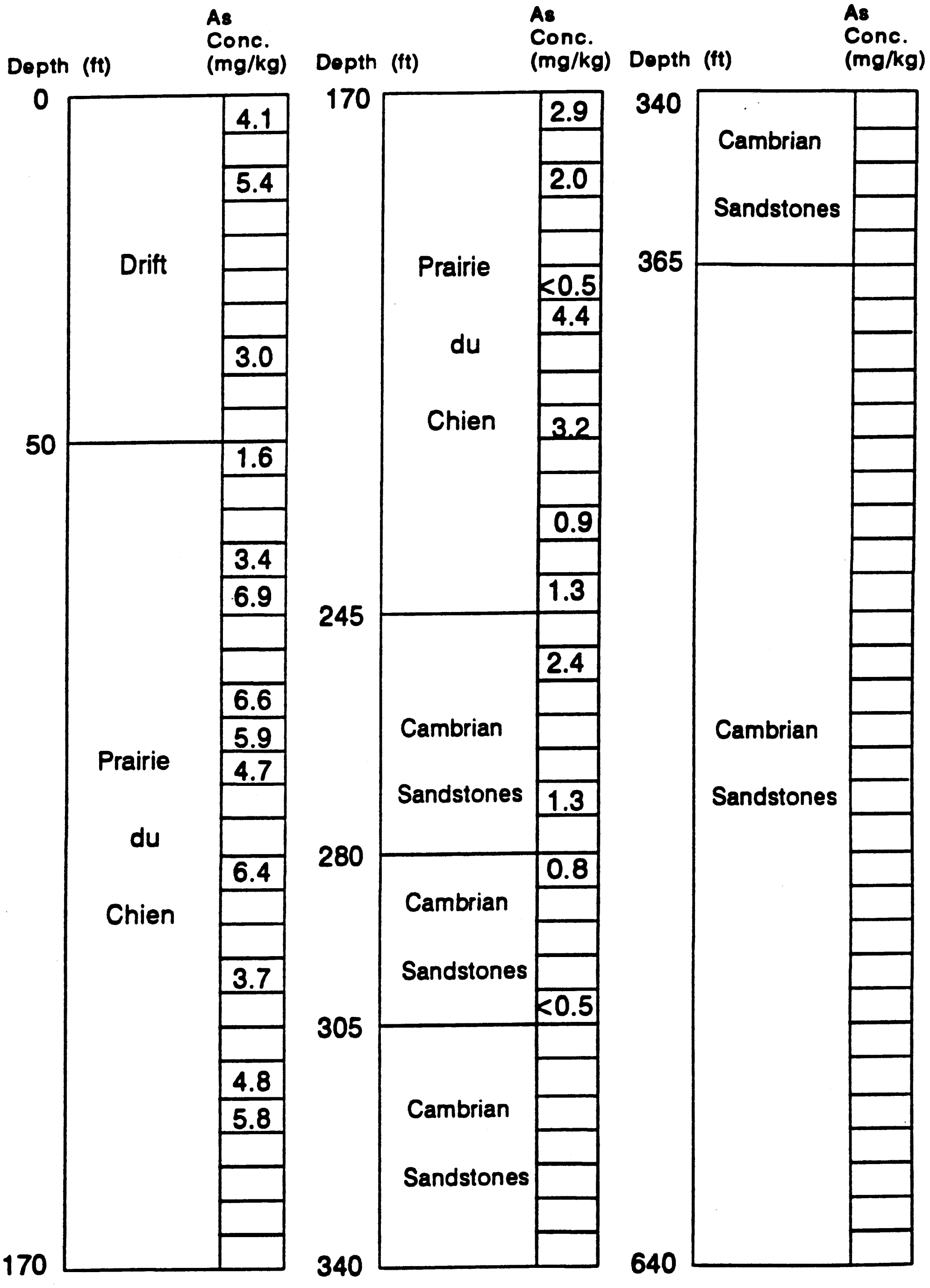
Fox River Tractor Company Well

The second well site chosen for arsenic analysis of drill cuttings was the Fox River Tractor Company well drilled in 1963, by Goldbeck Well Drilling. This well, located in Outagamie County, Grand Chute Township, SE1/4, SW1/4, Section 20, T21N, R17E was chosen because a descriptive lithology report was available for this well and drill cuttings were on file at the WGHNS repository. The well is cased with a 35.6 cm (14 in) diameter casing to 14.3 m (47 ft) and grouted with cement. A second casing with a 20.3 cm (8 in) diameter extends to a depth of 30.5 m (100 ft). The total well depth is 199.0 m (653 ft). The drill cutting samples were examined by J. M. Warren to determine lithology and formations present. According to the well log, drift material was encountered to a depth of 15.2 m (50 ft) and underlain by 59.4 m (195 ft) of Prairie du Chien Dolomite. However, the geological well log indicates that the interval between 15.2 m and 21.3 m (50 and 70 ft) may be Platteville/Galena Dolomite. The Prairie du Chien Dolomite is underlain by the Trempealeau Sandstone from 74.7 m (245 ft) to 83.8 m (275 ft). The Tunnel City unit was found from 83.8 m (275 ft) to 93.0 m (305 ft) underlain by the Ironton Sandstone to a depth of 111.3 m (365 ft). The Galesville Sandstone of the Elkmound Group was encountered at 111.3 m (365 ft) to the bottom of the well. The drill cuttings were sent directly to the WSLH for arsenic analysis. A copy of the well construction report can be found in Appendix IV.

Twenty-five drill cutting samples from the Fox River Tractor Company well were analyzed for arsenic. The results shows that arsenic concentrations remained relatively constant in all intervals analyzed (Figure 13). The well was drilled through drift then the Prairie du Chien which contained mostly dolomite. The dolomite layer in this well was unlike the Maple Leaf Dairy well in which the Prairie du Chien Group was composed of dolomite in the upper portion and sandstone in the lower portion. The Prairie du Chien Group at the Fox River Tractor well had relatively lower arsenic concentrations than the Maple Leaf Dairy well, probably because of the lack of sandstone in the formation.

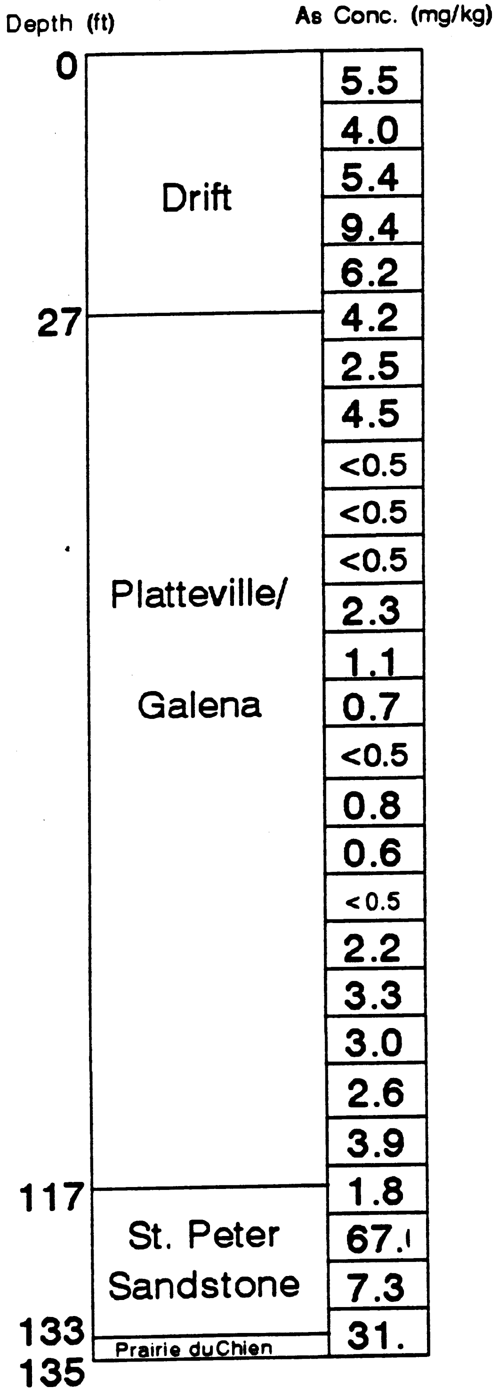
Donald Valence Well

The third well, located in Winnebago County, Clayton Township, SE1/4, SE1/4, Section 29, T20N, R16E chosen for drill cutting arsenic analysis was a private well owned by Donald Valence. This well was chosen based on the availability of a lithology report and drill cuttings. The Valence well is 15.2 cm (6 in) in diameter with a total depth of 41.1 m (135 ft). It was drilled by Schmidt's Rotary Well Drilling Water and Pump Service on April 26, 1990. According to the well log, clay, hardpan and stones were encountered to a depth of 8.2 m (27 ft) from the surface and underlain by 27.4 m (90 ft) of limestone. Shale and sandstone were encountered at 35.7 m (117 ft) to 40.5 m (133 ft). This was underlain by limestone at 40.5 m (133 ft) throughout the rest of the well. The well is cased to 12.8 m (42 ft) and grouted with cement to a depth of 12.5 m (41 ft). A copy of the well construction report and lithology report is in Appendix IV. The Donald Valence well drill cutting results are shown in Figure 14.



Note: Blank squares represent intervals not analyzed

Figure 13. Drill Cutting Results for Fox River Tractor Well



Note: Blank square represents interval not analyzed

Figure 14. Drill Cutting Results for Donald Valence Well

Arsenic concentrations are relatively higher in the St. Peter Sandstone than in other formations comprising the well. The upper Prairie du Chien unit also showed relatively higher arsenic concentrations than those found in the Platteville/Galena Dolomite. This observation supports the data obtained from packer testing and drill cutting analysis at other sites. The relatively low arsenic concentration found at the contact between the St. Peter Sandstone and the lower Platteville/Galena Dolomite may be due to the sampling method. Typically only 2 to 3 g of sample are collected from an entire five-foot drilling interval. A grab sample may have been taken when the well driller began drilling at 35.1 m (115 ft). If this were the case, it would have been a sample from the Platteville/Galena Dolomite and not the contact zone.

The WGNHS lithology report for the Valence well indicates the presence of pyrite (Appendix IV) which may correlate with the presence of arsenic. However, examination of the results of the drill cutting analysis for arsenic shows no apparent correlation with the presence of pyrite. This link may exist but due to sampling methods for collecting drill cuttings, it may not be possible to establish such a relationship.

Dick Olson Well

The final site selected for drill cutting arsenic analysis was the well owned by Sue and Dick Olson, located in Outagamie County, Osborn Township, NW1/4, NW1/4, Section 8, T23N, R18E. The well was originally constructed by Bill Van De Yacht on November 14, 1984, to a depth of 30.8 m (101 ft). According to the original well log, clay was encountered to a depth of 2.7 m (9 ft) and is underlain by 12.5 m (41 ft) of limestone. Sandstone was encountered at 15.2 m (50 ft) below the surface extending to the bottom of the well. The well was originally cased to 12.8 m (42 ft) with black steel casing grouted in place. The original Olson well construction report is in Appendix IV. On March 15, 1993, the well was reconstructed to a depth of

91.4 m (300 ft). During reconstruction, the Cambrian sandstones were encountered directly below the St. Peter Sandstone at 70.1 m (230 ft) and extended to 91.4 m (300 ft).

The results of the drill cuttings analysis for the Olson well are shown in Figure 15. Drill cuttings were available only from the newer (deeper) portion of the well. Thus, no drill cuttings were available above 33.5 m (110 ft), the contact between the Platteville/Galena Dolomite and the St. Peter Sandstone. Unfortunately this is the most important zone since it is believed to contribute arsenic to groundwater. The results from the analysis indicate that the arsenic concentrations are relatively uniform throughout the rock column. There are no exceptionally high arsenic zones, although the upper Cambrian sandstone has a somewhat higher concentration of arsenic than other zones. Several intervals were not analyzed for arsenic because of cost constraints.

Data Interpretation

The private well sample results indicate a significant number of wells in Outagamie County exceed the health advisory for arsenic. One well in Winnebago County of the 164 sampled exceeded the health advisory for arsenic. Due to the complexity of the bedrock geology, groundwater flow and the number of samples exceeding the health advisory (only one in Winnebago County), interpretation of the pattern arsenic contamination of privates wells will be primarily limited to Outagamie County. The private wells exceeding the health advisory for arsenic tend to be within a 8.0 km (5 mile) area of the St. Peter Sandstone subcrop. The St. Peter Sandstone subcrop refers to the area where the St. Peter Sandstone is nearest to the surface. Since most private wells within Outagamie and Winnebago Counties range between 30.4 m and 48.8 m (100 and 160 ft) in total depth, the St. Peter Sandstone would be the strata most wells would tap. Wells located outside this area most likely would not

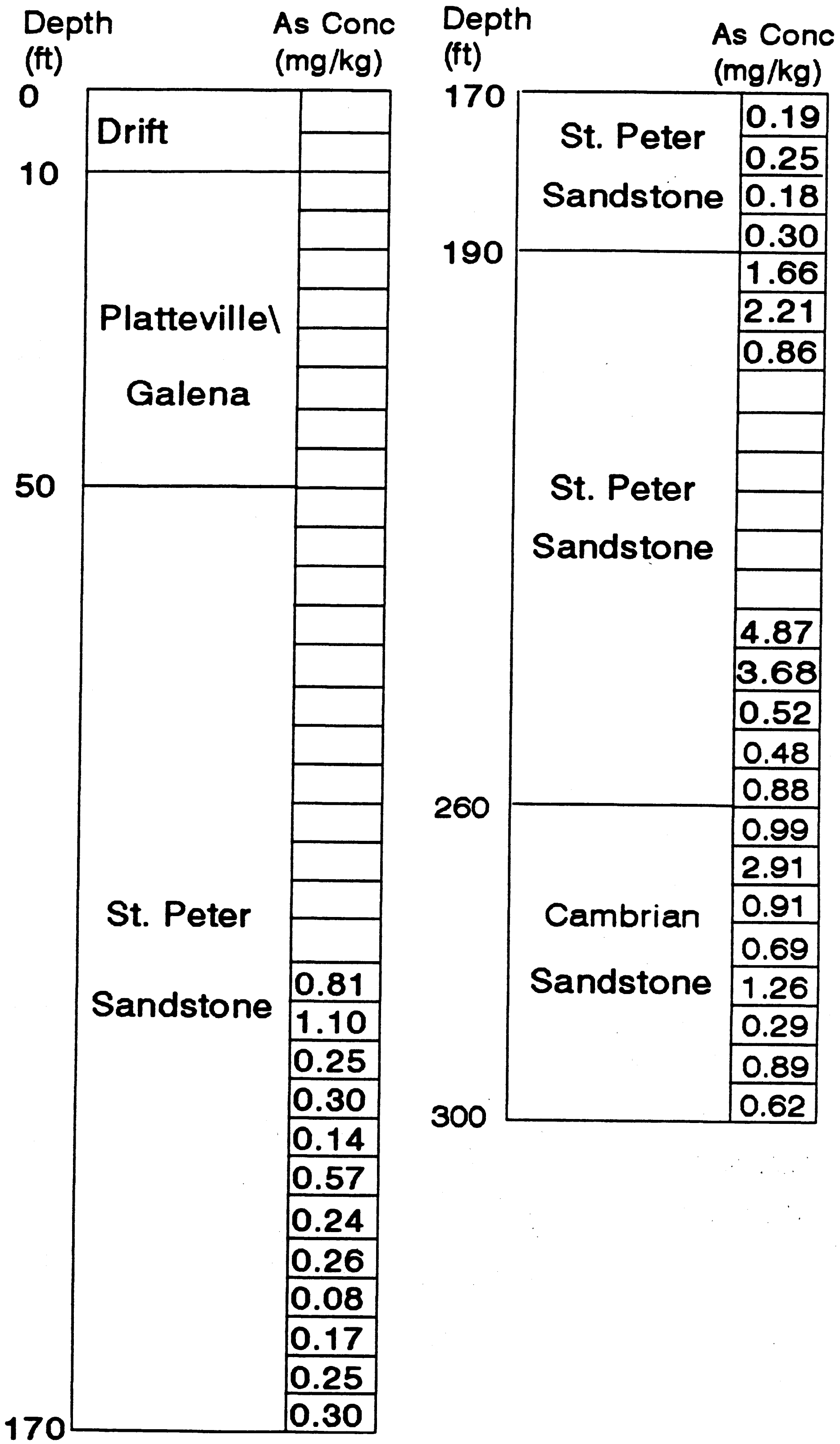


Figure 15. Drill Cutting Results for Olson Well

draw water from zones within the St.Peter Sandstone because it lies too deep or it is non-existent. The St. Peter Sandstone dips to the southeast at a rate of 4.7 m/km (25 ft/mile) (Olcott, 1966). Those private wells located outside the 8.0 km (5 mile) boundary from the St. Peter Sandstone that are deeper than normal, however, may encounter the St. Peter Sandstone. Municipal wells tend to have greater depths than private wells and, therefore, may extend into the St. Peter Sandstone when located greater than 8.0 km (5 miles) from the St. Peter Sandstone trend. However, because most municipal wells are quite deep, they may draw water from several different geologic units within the subsurface. Thus, if the St. Peter Sandstone was contributing arsenic to the municipal supply, it may be diluted with the water received from other geologic units. This is apparent also from the arsenic packer test results from the Seymour test wells drilled by the USGS. Three wells were constructed by the USGS and the WGNHS to study the area of source groundwater for Brown County. Three wells (W131-OU-416, W130-OU-417 and W129-OU-418) were drilled across the theoretical groundwater divide. A groundwater divide separates the groundwater that flows naturally into one particular basin from that which flows naturally into a neighboring basin. Packer tests were performed by WGNHS and USGS on all three wells to determine water quality and quantity. The packer test interval varied from test to test and ranged from 19.2 to 57.9 m (63 to 190 ft). This difference in intervals would effect the dilution of the arsenic in the sample because the larger the well column from which the water is drawn the greater the likelihood for dilution and therefore a reduction in arsenic concentration.

Well W131-OU-416 water samples extracted from the packer intervals contained arsenic ranging between < 10 μg/L and 34 μg/L which were higher than W130-OU-417 and W129-OU-418, therefore, it was chosen for arsenic analysis of drill cuttings. Low concentrations of arsenic between < 10 μg/L and 12 μg/L were detected in wells W130-OU-417 and W129-OU-418. None of the water samples extracted from the packer intervals from the three wells exceeded the drinking water standard for arsenic.

The groundwater divide as delineated by the WGNHS separates Outagamie County almost in half. This divide separates groundwater flow direction in Outagamie County into either a southeasterly flow direction or a westerly flow direction. Most wells that exceed the health advisory for arsenic are located east of the groundwater divide. When groundwater contamination is present due to point (human-made) sources, areas of contamination tend to be distributed down gradient of the source. Because arsenic contamination in Outagamie County is spread linearly along the groundwater divide, the pattern suggests that the arsenic is not originating from a single point source.

Wells with high arsenic levels may receive larger quantities of water from zones within the subsurface with higher arsenic mineral content (Glenwood Member of the St.Peter Sandstone). The Glenwood Member is known to be highly mineralized. Therefore, the water derived from this zone within the well may contain a higher arsenic content due to the dissolution of those minerals. Arsenic concentrations in the well water are the results of a complex interplay of minerals present in the aquifer supplying the water, the flow of water through the aquifer, the geochemistry of the groundwater, microorganisms present and a host of other geochemical conditions.

To further rule out the possibility of multiple point sources as a reason for elevated arsenic levels in groundwater, a search for arsenic pesticide storage facility locations was undertaken. Arsenic-based pesticides, such as sodium arsenite, were used in the 1930's and 1940's in Wisconsin for grasshopper control. The search found only one site each in Outagamie and Winnebago Counties, that reportedly stored arsenic-based pesticides in the 1940's. The Outagamie County highway shop in Appleton, Wisconsin, was reported in May, 1940, to have two drums outside the shop from a 1938 shipment. Both drums were reported to be located outside the shop in poor storage. Winnebago County was also reported to have two drums at its highway shop in Oshkosh. These drums were reported as part of a 1938 shipment and in fair condition and in good storage. There are no further records of storage, disposal or use of these materials beyond May, 1943, at either location. These two facilities could not possibly supply the arsenic contamination to all affected wells. If these sources were major contributors to arsenic contamination, the highest levels of arsenic in well water would have been found near the two garages. This was not the case. The St. Peter Sandstone subcrop is paralleled by arsenic contaminated wells over a 35.4 km (22 mile) linear distance. In summary, a single human-made point source or multiple point sources of the arsenic contamination in the private wells is deemed highly unlikely. This is because of the linear distribution pattern of the arsenic contamination over this trend.

The drill cutting analysis strongly supports the theory that the arsenic in well water in the two counties comes from natural sources. Although arsenic concentrations in the groundwater cannot be predicted from drill cutting results, a relative basis of where to expect high arsenic concentrations can be predicted. The drill cutting results suggest that higher arsenic concentrations should exist in the upper portions of the St. Peter Sandstone and possibly the lower portion of the Platteville/Galena Formation.

The drill cutting results are supported by the packer testing results. Even though the contact between the St. Peter Sandstone and the Platteville/Galena Formation was not directly tested, the packer tests showed a marked increase in arsenic concentration in the upper portion of the St. Peter Sandstone. The lower St. Peter Sandstone and the Prairie du Chien units had much lower arsenic concentration in the groundwater received from those aquifers. The results suggest that one should avoid extracting well water from the upper portion of the St. Peter Sandstone aquifer to minimize arsenic levels in groundwater supplies.

National Uranium Resource Evaluation (NURE) Data

The United States Atomic Energy Commission initiated the National Uranium Resource Evaluation (NURE) program in 1973. The NURE was initiated to determine the available uranium resources and the potential for uranium exploration in the United States. One of the major programs initiated for data collection was the Hydrogeochemical and Stream Sediment Reconnaissance. The purpose of this program was to systematically sample groundwaters, surface waters, and sediments from lakes, springs, and streams. Sampling began in 1976, with authorization for analysis of elements other than uranium in 1977. Wisconsin was studied for various metals concentrations in natural waters in 1977.

In 1985, the USGS obtained responsibility for all NURE data and reports. The NURE data indicated that both Outagamie and Winnebago Counties had wells exceeding the preventative action limit for arsenic (5 μg/L). The data also showed that both Shawano and Waupaca Counties had wells that exceeded the preventative action limit for arsenic. The St. Peter Sandstone trend does extend north of Outagamie County into Shawano, Oconto and Marinette Counties. It also exists south of Winnebago County into Fond Du Lac, Dodge, Jefferson and other counties. A summary of the NURE data for 11 counties in northeastern Wisconsin is found in Table 8.

New Well Construction and Well Reconstruction

Three families with groundwater exceeding the health advisory for arsenic were advised that they may want to consider remediating their arsenic problem via reconstruction of their existing well or constructing a new well. All three constructions and reconstructions proved successful. The first well is located in the SE1/4, SW1/4, Section 13, T21N, R16E in the township of Greenville, in Outagamie County, Wisconsin. The well was analyzed initially by National Testing Laboratories

Table 8. Summary of Arsenic Data from the National Uranium Resource Evaluation Program (NURE)

County	Total Number of Samples	Maximum Arsenic Value (ppb)	Minimum Arsenic Value (ppb)	Average Arsenic Value (ppb)
Brown	31	2.0	.5	.66
Calumet	26	4.0	.5	.88
Florence	28	7.1	.5	1.12
Manitowoc	4	5.6	.5	2.63
Marinette	57	4.7	.5	.98
Oconto	66	8.5	.5	1.67
Outagamie	71	14.1	.5	2.72
Shawano	104	59.2	.5	1.89
Waupaca	89	15.2	.5	1.72
Waushara	63	7.6	.5	1.23
Winnebago	32	17.2	.5	2.48

at the request of the well owner, John Baumgart in April of 1988. The well water reportedly contained 240 μg/L total arsenic which exceeded the health advisory. The WDNR was notified of the results and resampled the well. The results reported by the WSLH were 630 μg/L total arsenic and 2120 mg/L total solids. The Baumgarts were issued a health advisory and advised not to use their water for drinking or food preparation. The Baumgart's decided to reconstruct their existing well.

The Baumgart's original well was constructed on October 3, 1978, by Wagner Brothers Well Drilling Inc. to a total depth of 43.3 m (142 ft). According to the well construction report, red clay was encountered to a depth of 9.1 m (30 ft). This was underlain by 1.5 m (5 ft) of gravel. Hardpan was encountered from 10.7 m (35 ft) to 13.7 m (45 ft). The hardpan was underlain by 24.4 m (80 ft) of Platteville/Galena Dolomite. The St. Peter Sandstone was encountered from 38.1 m (125 ft) to 43.3 m (142 ft) below the Platteville/Galena Dolomite. The well was cased to a depth of 13.7 m (45 ft). A copy of the well construction report is in Appendix V.

Based on the well construction report, the WDNR advised the Baumgart's to grout the bottom of their existing well to eliminate well recharge from the St. Peter Sandstone which was believed to be the source of arsenic. Once grouted, the well supplied little water to the residence. The WDNR then advised the owner to abandon the existing well and to drill a new well on the property that would not extend into the St. Peter Sandstone formation. The well was abandoned on December 19, 1990, by Bill Van De Yacht.

A new well was constructed on November 30, 1990, by Bill Van De Yacht. The new well extended only into the Platteville/Galena Dolomite and does not draw water from the St. Peter Sandstone. A copy of the new Baumgart well construction report is in Appendix V. According to the well construction report clay was encountered to a depth of 12.2 m (40 ft). The clay is underlain by 2.7 m (9 ft) of gravel. Limestone was encountered from 14.9 m (49 ft) to the total well depth of 30.8 m

(101 ft). The well is cased to 15.2 m (50 ft). The well water was sampled by the WDNR on January 22, 1990, and analyzed for arsenic by the WSLH. The WSLH reported the arsenic concentration to be less than their quantifiable limit (10 μg/L). Thus, the arsenic contamination problem was avoided by drilling a new well that did not draw water from the St. Peter Sandstone.

The second well that was constructed because of arsenic contamination was owned by Mark Voster. The well is located in the SW1/4, SE1/4, Section 32, T22N, R17E in Center Township in Outagamie County, Wisconsin. The well was reported to contain 59 μg/L total arsenic from a February 6, 1991, sample and 74 μg/L total arsenic from a March 13, 1991, sample. Both results exceeded the health advisory for arsenic. Thus, the Voster's were advised by the WDNR not to use the water for drinking or food preparation. They were advised of alternatives for remediation of the arsenic problem which were: (1) reconstruction of the well; (2) drilling a new well; (3) purchasing bottled water or (4) purchasing an approved treatment device for the removal of arsenic. The Voster's decided to drill a new well.

The original Voster well was constructed on October 19, 1968, by Malcolm Veitch to a total well depth of 45.7 m (150 ft). According to the original well construction report (Appendix V), red clay was encountered to a depth of 3.7 m (12 ft) underlain by 2.1 m (7 ft) of hardpan. Gravel was noticed from 5.8 m (19 ft) to 7.0 m (23 ft). The well construction report indicates the presence of Platteville/Galena Dolomite from 7.0 m (23 ft) to 28.0 m (92 ft). St. Peter Sandstone was encountered directly under the Platteville/Galena Dolomite to the total well depth of 45.7 m (150 ft). The well was cased to a depth of 12.6 m (41.5 ft). The WDNR advised the Voster's to either drill a new well that extended below the St. Peter Sandstone or to drill shallower to avoid the St. Peter Sandstone. The original well was abandoned and a new well was drilled on May 4, 1991. The new well was constructed by Schmidt's Well Drilling to a total depth of 54.9 m (180 ft). According to the new well construction report (Appendix V) clay, stone, and gravel were encountered to a depth of 10.0 m (33 ft). This was underlain by Platteville/Galena Dolomite to a depth of 29.0 m (95 ft). The St. Peter Sandstone was encountered from 29.0 m (95 ft) to 53.3 m (175 ft), and underlain by a mixture of limestone, sandstone and shale from 53.3 m (175 ft) to the total well depth of 54.9 m (180 ft). The well casing extended from the surface to 47.2 m (155 ft). The new well was sampled on June 25, 1991, by the WDNR and analyzed by the WSLH for total arsenic. The arsenic concentration in the new well was reported to be less than detectable quantities, <10 μg/L. Thus, by drilling deeper and casing off the St. Peter Sandstone and Platteville/Galena contact, the arsenic concentration in the well was reduced.

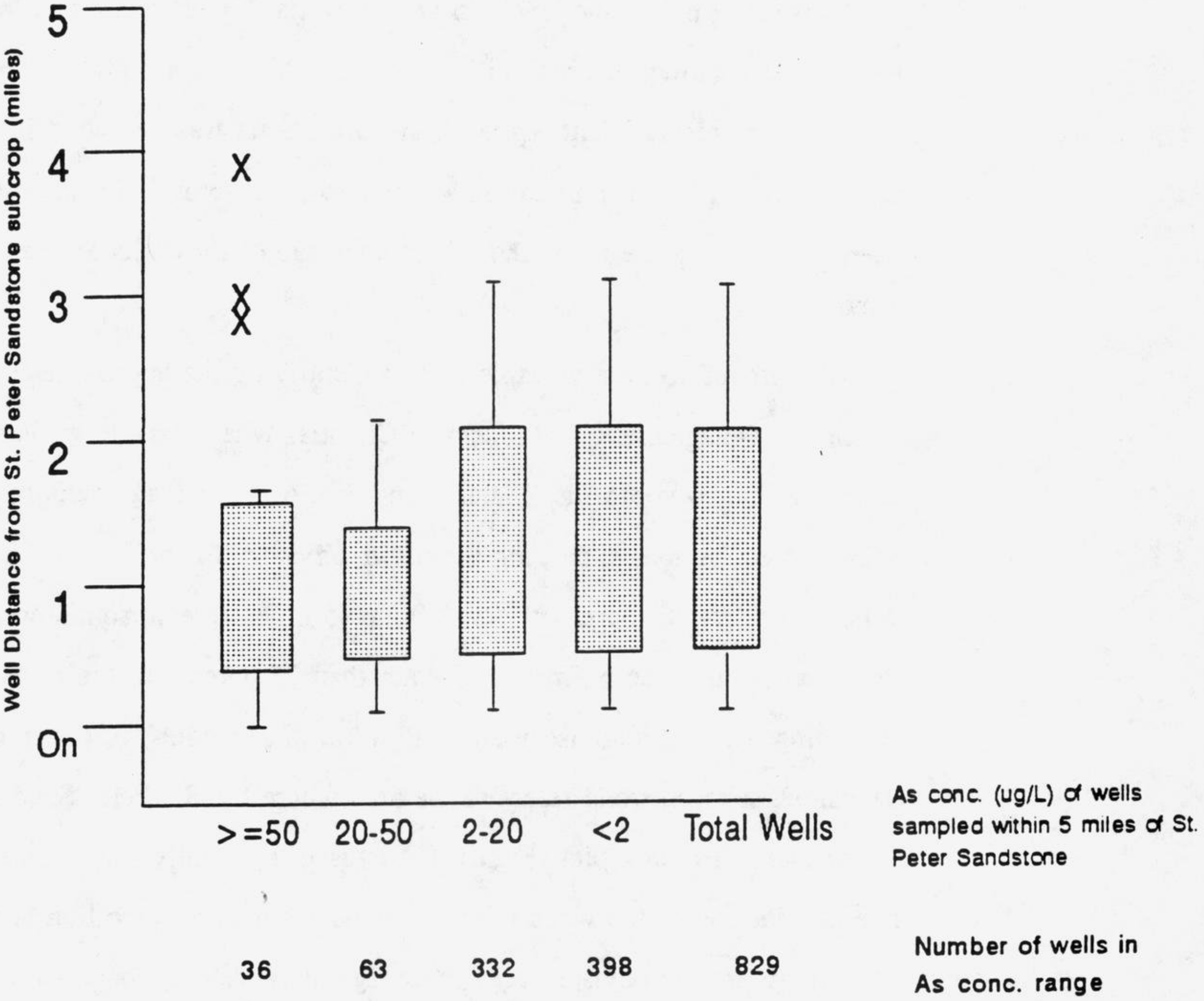
The Olson well was the third well that remediation techniques were used to lower the arsenic concentration in the well water. A lithological description of the Olson's original well and their reconstructed well is in Chapter 4. The original well construction report and a lithological summary of their reconstructed well are in Appendix V. The Olson's placed a liner in their deepened well to 45.7 m (150 ft). The liner prevented the well from drawing water from the upper portions of the St.Peter Sandstone, which was known from prior packer testing as contributing arsenic to the well. After the installation of the well liner, the well was resampled from an outside tap and was reported by the WSLH to contain 13 μg/L arsenic and 1.6 mg/L iron. This is a drastic reduction from 1200 μg/L arsenic and 87 mg/L iron, the values reported prior to remediation.

Remediation reduced the arsenic concentration in the three wells by eliminating the upper St. Peter Sandstone as a primary water source. In one case the well was drilled shallower, thus removing the St. Peter Sandstone as the source of water altogether. In the other cases, the wells were constructed deeper and the casing was extended beyond the upper St. Peter Sandstone preventing this zone from recharging the well.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

This study of arsenic levels in private wells in Outagamie and Winnebago Counties has shown that a significant number of wells are affected by high arsenic levels. The present health standard of 50 μg/L As was exceeded in 3.6 % of the wells tested. If the health advisory standard for arsenic is lowered to 5 μg/L as has been proposed by the EPA, then the percentage of the wells affected will increase to 39 %.

GIS proved to be a valuable tool in identifying the approximate geographic regions in Outagamie and Winnebago Counties where private wells are affected by naturally occurring arsenic (Plates 1 and 2). All of private wells in Outagamie and Winnebago Counties exceeding the health advisory for arsenic in Outagamie and Winnebago Counties are within a 8.0 km (5 mile) area surrounding the mapped St. Peter Sandstone subcrop trend. Greater than 75 percent of the private wells exceeding the health advisory are within 3.2 km (2 miles) of the trend. The St. Peter Sandstone subcrop trend refers to the area where the St. Peter Sandstone is nearest to the surface. The box plot (Figure 16) is used to visually summarize the arsenic data. The distribution of the wells within various arsenic concentration ranges were used to develop an arsenic advisory area in Outagamie and Winnebago Counties. Five values were used from the set of data: the upper and lower boundaries at 90 and 10 percent, respectively, the upper and lower quartiles (stippled areas) and the median. The number of wells within each arsenic concentration range and mile distance from the St. Peter Sandstone subcrop was calculated using GIS. Within each arsenic concentration range and distance from the St. Peter Sandstone subcrop, the median, quartiles, and upper and lower boundaries were calculated. For example, all well within Outagamie County with an As level equal to or greater than 50 μg/L were



Note: Outliers are not shown in arsenic concentrations greater than 50 ug/L

Figure 16. Locational Distribution (Box Plot) of Arsenic Concentrations in Private Wells in Outagamie County, Wisconsin

within 8.0 km (5 miles) of the St. Peter Sandstone subcrop. Ninety percent of these wells fell within 3.2 km (2 miles) of the St. Peter Sandstone subcrop. For this data set there were three outliers represented with X's. The outliers in this data set may be due to the Prairie du Chien sandstone zone contributing arsenic to the well water. This is supported by drill cutting results. One of the outliers may be due to a deeper private well. Since most wells containing arsenic fell within a 8.0 km (5 mile) range of the St. Peter Sandstone subcrop, a 8.0 km (5 mile) boundary around the St. Peter Sandstone subcrop was established as a well drillers and arsenic testing advisory area.

Since most private wells within Outagamie and Winnebago Counties range between 30.5 m and 48.8 m (100 and 160 ft) deep, wells within the advisory area are prone to draw water from the St. Peter Sandstone. Those located outside this area would not likely reach the St. Peter Sandstone. The St. Peter Sandstone is deeper to the east because it dips to the southeast at a rate of 4.7 m/km (25 ft/mile) (Olcott, 1966). Those private wells, located outside the 8.0 km (5 mile) boundary from the St. Peter Sandstone, that are drilled deeper than normal may encounter the formation and therefore may contain arsenic.

This study has provided substantial evidence that the arsenic found in the groundwater in Outagamie and Winnebago Counties is of natural origin. First, the pattern of contaminated wells is relatively widespread covering an area of approximately 580 km^2 (224 mi^2). The aerial extent of the contamination alone clearly suggests that the source of arsenic is of natural origin. Second, analysis of drill cuttings from various geologic formations, especially in the upper St. Peter Sandstone, have identified specific zones in various geologic strata with high levels of arsenic. Third, well packer tests have shown that groundwater from these zones have the highest levels of arsenic.

There are a number of natural sources that may possibly contribute to arsenic in groundwater. Arsenic tends to be associated with mineral deposits of sulfides and sulfo-salts (Boyle and Jonasson, 1973). Arsenic can be used as an indicator of the following types of deposits: Cu, Ag, Au, Zn, Cd, Hg, U, Sn, Pb, P, Sb, Bi, S, Se, Te, Mo, W, Fe, Ni, Co, Pt, because it is often associated with them. Arsenic is commonly found in certain types of mineral deposits, especially with the metals Cu, Ag, Zn, Hg, Pb, and Fe (Boyle and Jonasson, 1973). The principal carrier in rocks is pyrite, FeS_2 (Boyle and Jonasson, 1973). The presence of pyrite was examined in the Valence drill cuttings. The drill cuttings were reported to contain small amounts of pyrite. Pyrite may exist in layers within the upper St. Peter Sandstone or lower Platteville/Galena Dolomite and thus potentially contribute arsenic to groundwater. This is possible because often high iron and sulfate concentrations were found with high arsenic concentrations as observed in the Spreeman and Olson well water.

This research project has also identified alternatives for private wells so that users can eliminate or greatly reduce their exposure to arsenic in their drinking water supply. These alternatives are:

(1) purchase bottled water,
(2) install a state approved water treatment device such as a distillation or reverse osmosis unit,
(3) reconstruct an existing well, or
(4) drill a new well.

The data collected in this study provides the scientific basis for alternatives 3 and 4. We now know that when drilling a well in this area, if possible the St. Peter Sandstone unit should not be penetrated. If it is necessary to drill through the St. Peter Sandstone to obtain a sufficient volume of water, the upper portions should be cased off to prevent this part of the formation from supplying water to the well. Three private residences whose well water exceeded the health advisory for arsenic are now supplied well water from newly constructed wells based on these recommendations. All of the new wells reduced arsenic concentration in the water by removing the upper St. Peter Sandstone unit as the primary water source. One of the wells was drilled shallower thus removing the St. Peter Sandstone as the source of water altogether. The other two wells were drilled deeper and the casings extended beyond the upper St. Peter Sandstone excluding that portion from being part of the wells water source.

Based primarily on the results of this study, the WDNR has established guidelines for well drillers constructing wells within the advisory area of 8.0 km (5 mile) around the St. Peter Sandstone trend in Outagamie and Winnebago Counties (Figure 17). Well drillers and owners should realize that these established guidelines are not a guarantee that arsenic will be totally avoided in their new well water. The guidelines serve as an aid to reduce arsenic in water which recharges new wells based on current information. The guidelines to well drillers may change as more information is received regarding arsenic from Outagamie, Winnebago and surrounding counties. Well drillers constructing new wells within the arsenic advisory area are advised to follow the established guidelines. All private well owners residing in the arsenic advisory area should test their well water for arsenic and take appropriate measures to avoid arsenic exposure, if needed.

Municipal wells tend to be deeper than private wells and, therefore, may extend into the St. Peter Sandstone in areas outside the advisory area. However, because they have greater depth they may also draw water from several different geologic units within the subsurface and thus may benefit from dilution as is apparent when examining packer test results from the Seymour test wells drilled by the USGS. Nevertheless, if a new deep well is constructed for a potable water supply, the well driller or owner should have the water tested for arsenic.

The results of this investigation strongly suggest the need for further study. Since the St. Peter Sandstone is present in other parts of eastern and southern Wisconsin, these areas may also be effected by arsenic contamination and should be evaluated.

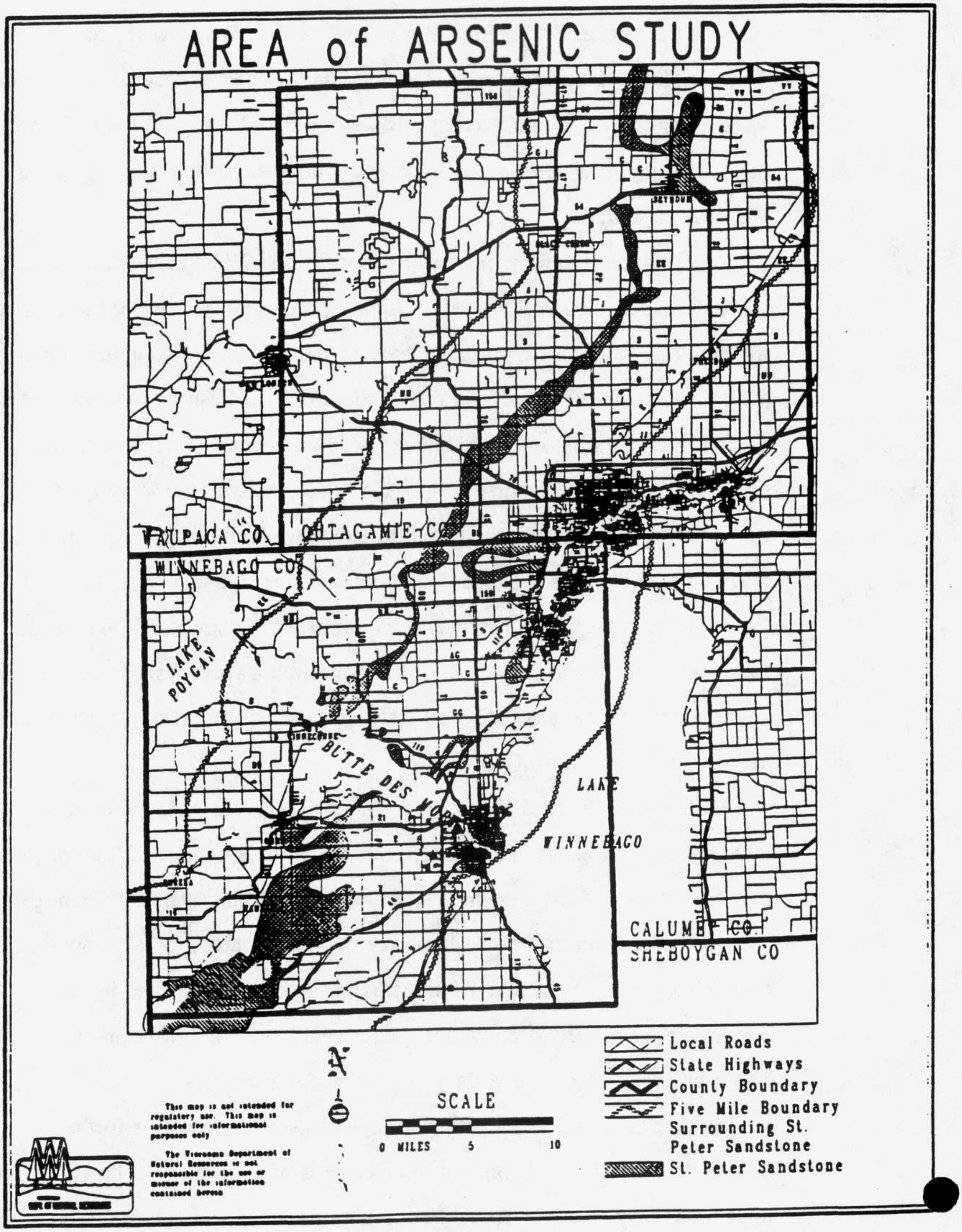


Figure 17. Arsenic Advisory Area for Outagamie and Winnebago Counties Wisconsin

In 1993, the WDNR expanded its arsenic studies to Shawano, Oconto, and Marinette Counties, Wisconsin. Selected private wells in these counties are to be sampled for arsenic. If any significant contamination levels are found, the WDNR and other agencies will need to take appropriate measures to inform the public.

A second recommendation is to perform health studies on individuals that have unknowingly been exposed to elevated arsenic levels from their water supply. Few studies exist on the effects of chronic exposure to arsenic. Such data would furnish additional information for the necessity of lowering the health advisory standard for arsenic from 50 μg/L to perhaps 5 μg/L.

A third recommendation is to further examine the cause of unusually low pH in groundwater. The Spreeman well water had an unusually low pH, which may be caused by the presence and oxidation of pyrite. However, this is only speculation, further study is required to determine the cause of this abnormal pH in the Spreeman and other wells with low pH problems (Porter and Schneider). The WDNR is currently conducting a study of the Porter well to determine whether the low pH found in this well is due to a natural or man-made source.

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APPENDIX I

Appendix I.

Groundwater Bottles and Preservation Methods Required by the SLOH for Chemical Analysis.
(Lindorff *et al*, 1987)

Parameter	Required Bottle Type (mL)	Volume Required (mL)	Preservation Method [1]	Volume of Preservative Required [2]
Alkalinity	625	50	Cool, 4°C	---
Chloride	625	25	none required	---
Metals - Ag,Al,As,Ba,Ca,Cd,Cu Fe,K,Mg,Mn,Na,Ni,Pb, Se,Sn,Zn,Hardness (all metals except Hg, and Cr^{+6})	250 Metals	250	HNO_3 to pH<2	2.5 mL 35% (8N) HNO_3 to pH<2
pH	625	25	Determine on site - Lab pH for reference only	---
Specific Conductance	625	50	Determine on-site	---
Sulfate	625	25	Cool, 4°C	---

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[1] Sample preservation was performed immediately upon sample collection.

[2] This is the volume of preservative generally found to be sufficient to achieve the proper pH. However, additional preservative may have been required in highly buffered samples. The final pH of preserved samples was verified with pH paper.

Appendix I. (continued)

Methods of Analysis used by SLOH				
Parameter	SLOH Method	Approved SDWA Method #	SDWA Reference Source	MDL[2] (µg/L)
Al, ICP	400.2	3120	SM	31.
SB, Furn	400.3	3113B	SM	2
As, Furn	400.3	3113B	SM	1
Ba, ICP	400.2	3120	SM	0.5
Be, ICP	400.2	3120	SM	0.3
Cd, Furn	400.3	3113B	SM	0.04
Cr, Furn	400.3	3113B	SM	1
Cu, ICP	400.2	3120	SM	3.
Cu, Furn[1]	400.3	3113B	SM	1
Fe, ICP	400.2	3120	SM	10.
Pb, Furn	400.3	3113B	SM	1.0
Mn, ICP	400.2	3120	SM	0.4
Hg, CV	540.1	245.1	EPA	0.03
Ni, ICP	400.2	3120	SM	6.
Se, Furn	400.3	3113B	SM	1
Ag, Furn	400.3	3113B	SM	0.2
Na, ICP	400.2	3120	SM	90.
Zn, ICP	400.2	3120	SM	8.
Ca, ICP	400.2	3120	SM	20.
Mg, ICP	400.2	3120	SM	20.
Alkalinity	115.1	310.1	EPA	1 mg/L
Chloride	140.4	325.2	EPA	0.1 mg/L
Color	170.1	2120B	SM	5 SU
Conductivity	115.1	120.1	EPA	1 µmho/cm
Cyanide	180.1	335.2	EPA	0.01 mg/L
Fluoride	190.3	10-109-12-2-A	Lachat	0.02 mg/L

Appendix I. (continued)

Methods of Analysis used by SLOH (continued)				
Parameter	SLOH Method	Approved SDWA Method #	SDWA Reference Source	MDL (mg/L)
Total Solids	330.1	160.3	EPA	10
Sulfate	370.2	375.2	EPA	1
Turbidity	380.1	180.1	EPA	1
Hardness	200.2	2340B	SM	6.
pH	300.0	150.1	EPA	0.1 SU

EPA	Methods for Chemical Analysis of Water and Wastes, USEPA, EPA-600/4-79-020 (1983).
SM	Standard Methods for the Examination of Water and Wastewater, 17th Edition (1989).
Lachat	Fluoride in water, Method 10-109-12-2-A, 1991. Available from Lachat Instruments, 6645 West Mill Road, Milwaukee, WI 53218.

[1] Used for sample with ≤100 µg/L when a lower MDL is desired.
[2] µg/L unless otherwise indicated

Notes:

Reporting limit for arsenic until December 1992 was 10 µg/L.
Limit of Detection (LOD) for arsenic determined December 1992 to be 1 µg/L.

Appendix I. (continued)

Drill Cutting Analysis Methods

Drill Cutting Digestion #	SLOH Method	LOD (mg/kg)	Reference Used
I323BST	750.1		EPA SW846, 3rd Edition, Section 3050, 1986.
Drill Cutting Analysis by	SLOH	LOD	Reference Used
	400.3	0.4	Methods for Chemical Analysis of Waters and Wastes, EPA-600/4-79-020, Method 206.5, 1979. Standard Methods, 17th Edition, Methods 3114, 1989.
Drill Cutting Analysis by Hydride	SLOH Method	Reporting Limit (mg/kg)	
	420.3	0.5	

APPENDIX II

Appendix II. Caliper Log Results - Spreeman Well

LAYNE-NORTHWEST COMPANY

Milwaukee, Wisconsin

CALIPER LOG

Job #: 69.5596-AP
Job Name: The Spreeman House/Wisconsin DNR

Well #: 1
Well Location: Steve & Christy Spreeman
N1245 Mayflower Drive
Appleton, WI 54915

Taken by: Vince and Mike Meindel
Date: February 3, 1993

FOOTAGE	DIAMETER	FOOTAGE	DIAMETER
300′	5.75"		
295	5.50		
290	5.73		
275...	6.00		
221...	6.25		
166...	6.50		
152...	6.75		
142	7.00		
136	6.75		
121	7.00		
112	6.75		
103	7.00		
91	6.75		
90	6.50		
35	6.00		

Layne

APPENDIX III

Appendix III. Gamma-ray Log Results - Spreeman Well

LAYNE-NORTHWEST COMPANY

Milwaukee, Wisconsin

GAMMA LOG

Job #: 60.5596-AP
Job Name: The Spreeman House/Wisconsin DNR

Well #: 1
Well Location: Steve & Christy Spreeman
N1245 Mayflower Drive
Appleton, WI 54915

Taken by: Vince & Mike Meindel
Date: February 3, 1993

FOOTAGE	SECONDS	FOOTAGE	SECONDS
303-301'	33	235-233'	142
301-299	14	233-231	129
299-297	10	231-229	150
297-295	14	229-227	139
295-293	12	227-225	183
293-291	13		
291-289	16	225-223	211
289-287	16	223-221	175
287-285	18	221-219	175
285-283	23	219-217	204
283-281	24	217-215	226
281-279	18	215-213	228
279-277	57	213-211	191
277-275	36	211-209	179
275-273	92	209-207	155
273-271	149	207-205	198
271-269	122	205-203	159
269-267	164	203-201	154
267-265	41	201-199	125
265-263	55	199-197	141
263-261	216	197-195	170
261-259	265	195-193	151
259-257	251	193-191	130
257-255	238	191-189	102
255-253	253	189-187	114
253-251	154	187-185	108
251-249	227	185-183	107
249-247	198	183-181	117
247-245	179	181-179	132
245-243	34	179-177	117
243-241	17	177-175	124
241-239	80	175-173	126
239-237	143	173-171	140
237-235	142	171-169	139

Appendix III. (continued) Gamma-ray Log Results - Spreeman Well

LAYNE-NORTHWEST COMPANY

Milwaukee, Wisconsin

GAMMA LOG

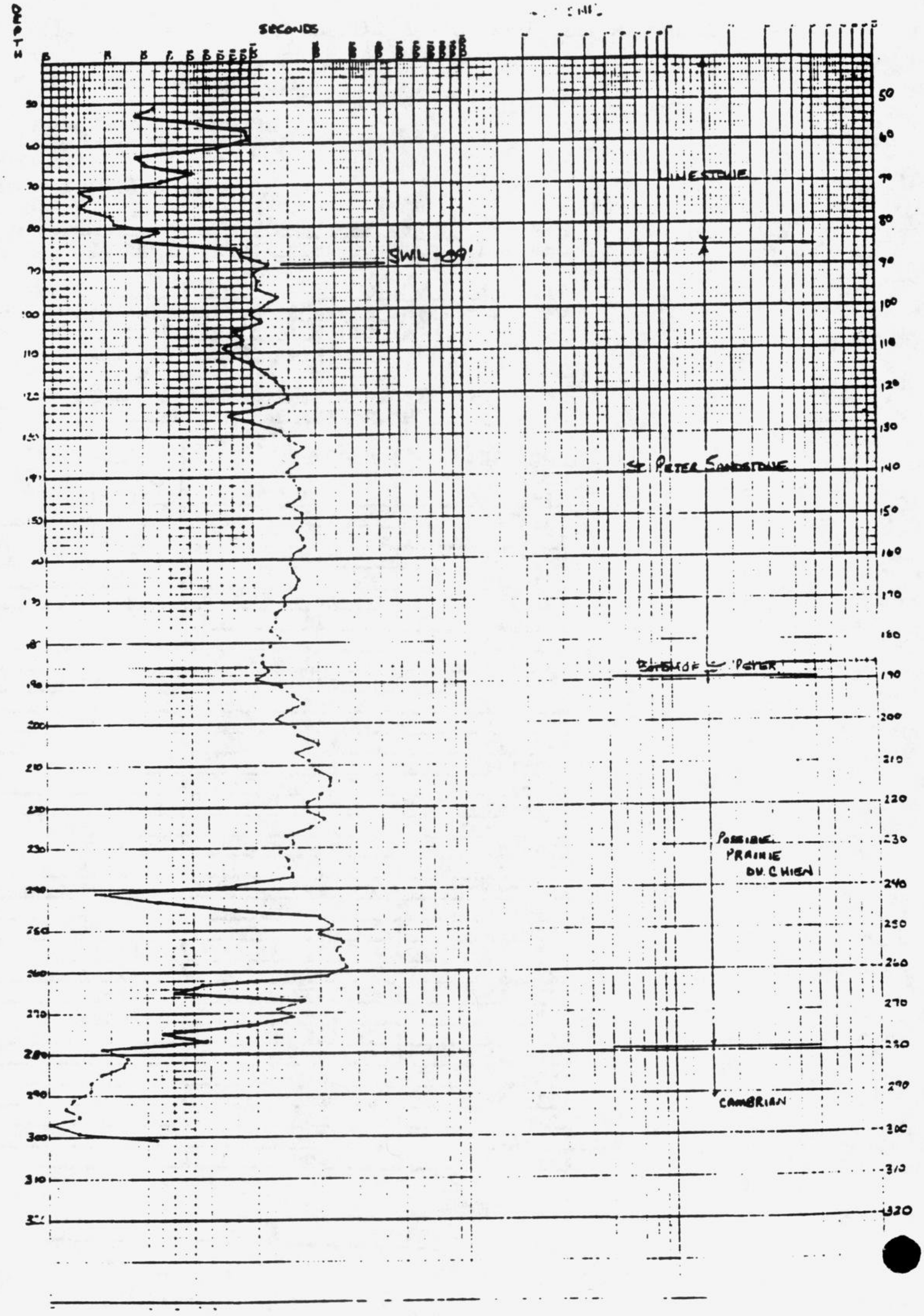
Job #: 60.5596-AP
Job Name: The Spreeman House/Wisconsin DNR

Well #: 1
Well Location: Steve & Christy Spreeman
N1245 Mayflower Drive
Appleton, WI 54915

Taken by: Vince & Mike Meindel
Date: February 3, 1993

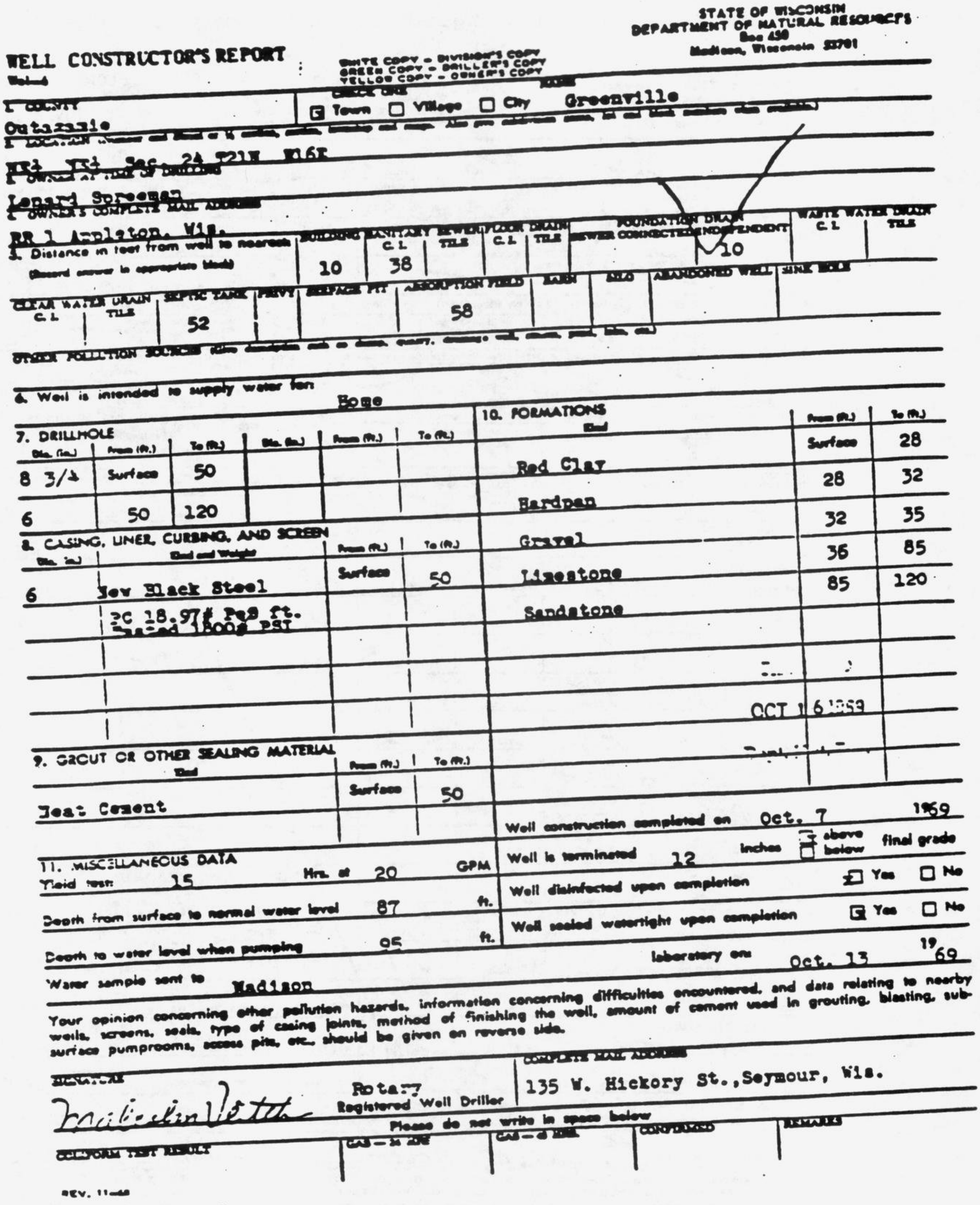
FOOTAGE	SECONDS	FOOTAGE	SECONDS
169-167'	157	103-101'	98
167-165	163	101-99	113
165-163	153	99-97	133
163-161	147	97-95	104
161-159	154	95-93	105
159-157	174	93-91	102
157-155	172	91-89	120
155-153	161	89-87	89
153-151	171	87-85	84
151-149	171	85-83	27
149-147	146	83-81	36
147-145	169	81-79	22
145-143	167	79-77	21
143-141	158	77-75	15
414-139	146	75-73	17
139-137	163	73-71	15
137-135	156	71-69	37
135-133	174	69-67	32
133-131	149	67-65	31
131-129	136	65-63	23
129-127	101	63-61	69
127-125	77	61-59	95
125-123	126	59-57	94
123-121	147	57-55	56
121-119	143	55-53	26
119-117	130	53-51	34
117-115	116		
115-113	100		
113-111	82		
111-109	74		
109-107	90		
107-105	83		
105-103	110		

Appendix III. (continued) Gamma-ray Log Results - Spreeman Well



APPENDIX IV

Appendix IV. (continued) Original Spreeman Well Construction Report



STATE OF WISCONSIN
DEPARTMENT OF NATURAL RESOURCES
Box 450
Madison, Wisconsin 53701

WELL CONSTRUCTOR'S REPORT
Wisconsin

WHITE COPY – DIVISION'S COPY
GREEN COPY – DRILLER'S COPY
YELLOW COPY – OWNER'S COPY

1. COUNTY: Outagamie

CHECK ONE: ☒ Town ☐ Village ☐ City — NAME: Greenville

2. LOCATION [illegible]: NE¼ NE¼ Sec. 24 T21N R16E

3. OWNER AT TIME OF DRILLING: Lenard Spreeman

4. OWNER'S COMPLETE MAIL ADDRESS: RR 1 Appleton, Wis.

5. Distance in feet from well to nearest: (Record answer in appropriate block)

BUILDING	SANITARY SEWER C.I.	SANITARY SEWER TILE	FLOOR DRAIN C.I.	FLOOR DRAIN TILE	FOUNDATION DRAIN SEWER CONNECTED	FOUNDATION DRAIN INDEPENDENT	WASTE WATER DRAIN C.I.	WASTE WATER DRAIN TILE
10	38					10		

CLEAR WATER DRAIN C.I.	CLEAR WATER DRAIN TILE	SEPTIC TANK	PRIVY	SEEPAGE PIT	ABSORPTION FIELD	BARN	SILO	ABANDONED WELL	SINK HOLE
		52			58				

OTHER POLLUTION SOURCES [illegible]

6. Well is intended to supply water for: Home

7. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
8 3/4	Surface	50			
6	50	120			

8. CASING, LINER, CURBING, AND SCREEN

Dia. (in.)	Kind and Weight	From (ft.)	To (ft.)
6	New Black Steel PC 18.97# Per ft. Tested 1800# PSI	Surface	50

9. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)
Neat Cement	Surface	50

10. FORMATIONS

Kind	From (ft.)	To (ft.)
	Surface	28
Red Clay	28	32
Hardpan	32	35
Gravel	36	85
Limestone	85	120
Sandstone		

OCT 16 1969

Well construction completed on Oct. 7 1969

Well is terminated 12 inches ☒ above ☐ below final grade

Well disinfected upon completion ☒ Yes ☐ No

Well sealed watertight upon completion ☒ Yes ☐ No

11. MISCELLANEOUS DATA

Yield test: 15 Hrs. at 20 GPM

Depth from surface to normal water level 87 ft.

Depth to water level when pumping 95 ft.

Water sample sent to Madison laboratory on: Oct. 13 1969

Your opinion concerning other pollution hazards, information concerning difficulties encountered, and data relating to nearby wells, screens, seals, type of casing joints, method of finishing the well, amount of cement used in grouting, blasting, sub-surface pumprooms, access pits, etc., should be given on reverse side.

SIGNATURE: Malcolm Vette

Rotary
Registered Well Driller

COMPLETE MAIL ADDRESS: 135 W. Hickory St., Seymour, Wis.

Please do not write in space below

COLIFORM TEST RESULT	GAS — 24 HRS	GAS — 48 HRS	CONFIRMED	REMARKS

REV. 11-68

Appendix IV. (continued) Original Olson Well Construction Report

State of Wisconsin
Department of Natural Resources
Private Water Supply
Box 7921
Madison, Wisconsin 53707

NOTE:
White Copy – Division's Copy
Green Copy – Driller's Copy
Yellow Copy – Owner's Copy

WELL CONSTRUCTOR'S REPORT
Form 3300–15 Rev. 2-79

NOV 2 6 1

COUNTY Outagamie

CHECK (✓) ONE: ☑ Town ☐ Village ☐ City Name Osborn

2. LOCATION ¼ Section or Gov't. Lot SW Section 8 Township Range 23N 18E

OR – Grid or Street No. Street or Road Name French

AND – If available subdivision name, lot & block No.

3. NAME ☑ OWNER ☐ AGENT AT TIME OF DRILLING CHECK (✓) ONE Dick Olsen

ADDRESS Rd

POST OFFICE Seymour, Wi. ZIP CODE

4. Distance in feet from well to nearest: (Record answer in appropriate block)

Building	Sanitary Bldg. Drain C.I.	Sanitary Bldg. Drain Other	Sanitary Bldg. Sewer C.I.	Sanitary Bldg. Sewer Other	Floor Drain Connected To: C.I. Sewer	Floor Drain Connected To: Other Sewer	Storm Bldg. Drain C.I.	Storm Bldg. Drain Other	Storm Bldg. Sewer C.I.	Storm Bldg. Sewer Other
12			60							

Street Sewer San.	Street Sewer Storm	Other Sewers C.I.	Other Sewers Other	Foundation Drain Connected to: Sewer	Foundation Drain Connected to: Clearwater Dr.	Foundation Drain Connected to: Sewage Sump	Foundation Drain Connected to: Clearwater Sump	Sewage Sump C.I.	Sewage Sump Other	Clearwater Sump	Septic Tank	Holding Tank	Sewage Absorption Unit: Seepage Pit	Sewage Absorption Unit: Seepage Bed	Sewage Absorption Unit: Seepage Trench	Manure Hopper or Retention or Pnuematic Tank
											70			50		

Privy	Pet Waste Pit	Pit Nonconforming Existing: Well	Pit Nonconforming Existing: Pump	Pit Nonconforming Existing: Tank	Subsurface Pumproom Nonconforming Existing	Barn Gutter	Animal Barn Pen	Animal Yard	Silo With Pit	Glass Lined Storage Facility	Silo w/o Pit	Earthen Silage Storage Trench Or Pit	Earthen Manure Basin

Temporary Manure Stack or Platform	Watertight Liquid Manure Tank or Basin	Manure Pressure Pipe	Subsurface Gasoline or Oil Tank	Waste Pond or Land Disposal Unit (Specify Type)	Manure Storage Basin: Concrete Floor Only	Manure Storage Basin: Concrete Floor and Partial Concrete Walls	Other (Describe)

5. Well is intended to supply water for: Home

6. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
9	Surface	41			
6	41	101			

7. CASING, LINER, CURBING AND SCREEN

Dia. (in.)	Material, Weight, Specification Mfg. & Method of Assembly	From (ft.)	To (ft.)
6	New blk stl	Surface	42
	Pl. end welded		
	ASTM, A53 B		
	18.97 280		
	[illegible]		

8. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)
~~[illegible]~~	Surface	41
Grout		

9. FORMATIONS

Kind	From (ft.)	To (ft.)
Clay	Surface	9
Limestone	9	50
Sandstone	50	101

10. TYPE OF DRILLING MACHINE USED

☐ Cable Tool
☐ Rotary-air w/drilling mud
☐ Rotary-w/drilling mud
☑ Rotary-hammer w/drilling mud & air
☐ Rotary-hammer & air
☐ Reverse Rotary
☐ Jetting with ☐ Air ☐ Water

Well construction completed on 11-16 84

Well is terminated 12 inches ☑ above ☐ below final grade

Well disinfected upon completion ☑ Yes ☐ No

Well sealed watertight upon completion ☑ Yes ☐ No

11. MISCELLANEOUS DATA

Yield Test: 2 Hrs. at 30 GPM

Depth from surface to normal water level 40 Ft.

Depth of water level when pumping 60 Ft. Stabilized ☑ Yes ☐ No

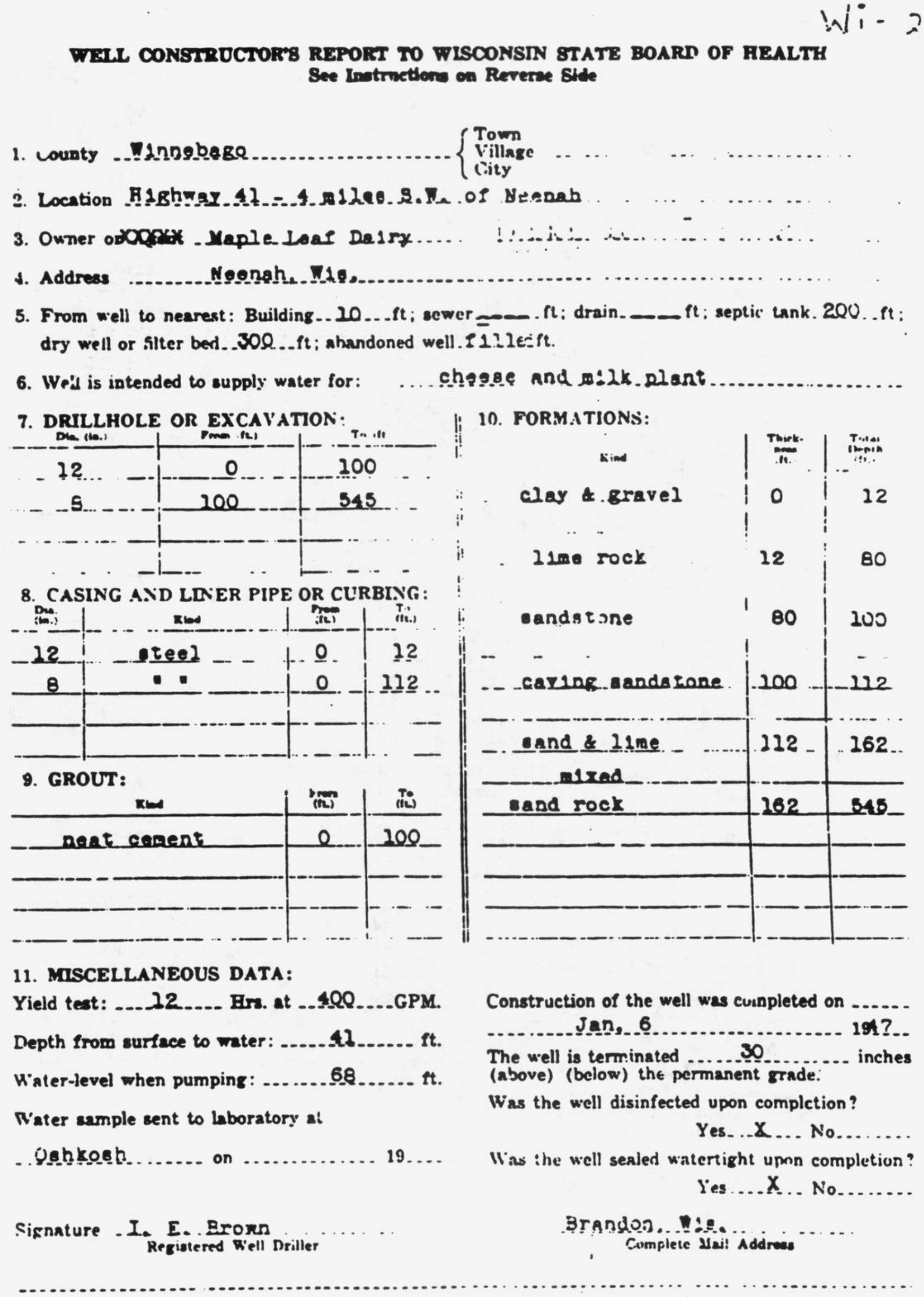
Water sample sent to Madison laboratory on 12-6 84

Your opinion concerning other pollution hazards, information concerning difficulties encountered, and data relating to nearby wells, screens, seals, method of finishing the well, amount of cement used in grouting, blasting, etc., should be given on reverse side.

Signature Bill Van De Yacht Registered Well Driller

Business Name and Complete Mailing Address
Van De Yacht Bros. Well Drilling
3383 Oak Forest Drive
Green Bay, WI 54303

Appendix IV. Maple Leaf Dairy Well Construction Report



Wi - 22

WELL CONSTRUCTOR'S REPORT TO WISCONSIN STATE BOARD OF HEALTH
See Instructions on Reverse Side

1. County Winnebago { Town Village City
2. Location Highway 41 - 4 miles S.W. of Neenah
3. Owner or XXXX Maple Leaf Dairy
4. Address Neenah, Wis.
5. From well to nearest: Building 10 ft; sewer — ft; drain — ft; septic tank 200 ft; dry well or filter bed 300 ft; abandoned well filled ft.
6. Well is intended to supply water for: cheese and milk plant

7. DRILLHOLE OR EXCAVATION:

Dia. (in.)	From (ft.)	To (ft.)
12	0	100
8	100	545

8. CASING AND LINER PIPE OR CURBING:

Dia. (in.)	Kind	From (ft.)	To (ft.)
12	steel	0	12
8	" "	0	112

9. GROUT:

Kind	From (ft.)	To (ft.)
neat cement	0	100

10. FORMATIONS:

Kind	Thickness (ft.)	Total Depth (ft.)
clay & gravel	0	12
lime rock	12	80
sandstone	80	100
caving sandstone	100	112
sand & lime	112	162
mixed sand rock	162	545

11. MISCELLANEOUS DATA:

Yield test: 12 Hrs. at 400 GPM.

Depth from surface to water: 41 ft.

Water-level when pumping: 68 ft.

Water sample sent to laboratory at Oshkosh on 19

Construction of the well was completed on Jan. 6 1947

The well is terminated 30 inches (above) (below) the permanent grade.

Was the well disinfected upon completion? Yes X No

Was the well sealed watertight upon completion? Yes X No

Signature I. E. Brown
Registered Well Driller

Brandon, Wis.
Complete Mail Address

Appendix IV. (continued) Maple Leaf Dairy Lithology Report

W1-22

MAPLE LEAF DAIRY WELL, NEENAH, WIS. NE 1/4, NE 1/4
4 m. SW of Noonah on U. S. 41 Sec. ~~26?~~ 1, T. ~~20~~ 19 N., R. 16 E.
I. E. Brown, Driller, 1946 136349-136386
Samples examined by F. T. Thwaites, Nos. 130406-130468;

Alt 785' ETM

D	12	0-12	12	Clay and gravel, no sample
PLATT	63	12-60	48	Dolomite, light gray
		60-70	10	Dolomite, blue-gray to light gray
		70-75	5	Sandstone, fine, light gray, dolomitic
SP	20	75-90	15	Sandstone, fine to medium, light gray
		90-95	5	Sandstone, medium to fine, light gray, dol.
LOWER MAG	120	95-155	60	Dolomite, light gray; some chert, white; little shale, green-gray
		155-160	5	Sandstone, medium to fine, light grey, very d
		160-170	10	Dolomite, light gray
		170-175	5	Sandstone, fine, lt.gy, dol; chert, white, oo
		175-190	15	Sandstone, medium to fine, light gray, dol.
		190-215	25	Sandstone, fine, red, some gray, quartzitic
TREM	45	215-225	10	Sandstone, fine, gray, dolomitic
		225-245	20	Siltstone, red, dolomitic
		245-260	15	Siltstone, sandy, pink, dolomitic
FRANCONIA	145	260-290	30	Sandstone, fine to medium, pink, dolomitic, glauconitic
		290-300	10	Sandstone, fine to medium, light grey, dol.
		300-310	10	Sandstone, fine to medium, pink, dol, glauc.
		310-315	5	Sandstone, fine to medium, lt.gy, dol, glauc.
		315-325	10	Sandstone, fine, lt.gy, very dol, glauconitic
		325-340	15	Sandstone, fine to medium, lt.gy, dol; sh, gn
		340-350	10	No samples
		350-360	10	Dolomite, silty, sandy, light gray
		360-370	10	Dolomite, sandy, silty, pink
		370-380	10	Sandstone, fine to medium, pink-gray, dol.
		380-415	35	Sandstone, fine to medium, light gray, dolomitic
DRESBACH	130	415-425	10	Sandstone, medium to fine, light gray
		425-465	40	Sandstone, fine to medium, light gray, dolomitic
		465-485	20	Sandstone, medium to fine, light gray
		485-495	10	Sandstone, fine to medium, light gray
		495-505	10	Sandstone, fine to medium, light gray, dol.
		505-520	15	Sandstone, fine to medium, pink
		520-525	5	Sandstone, fine to coarse, light gray
		525-530	5	Sandstone, fine to medium, light grey
		530-545	15	Sandstone, medium to fine, light gray; no sam

Formations: Drift; Platteville; St. Peter ; Lower Magnesian (Prairie du Chien); Trempealeau; Franconia; Dresbach (Galesville)
Tested 12 hours at 400 g.p.m. specific capacity = 14.75 g.p.m./ft.

Appendix IV. (continued) Fox River Tractor Litholgy Report

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No. Ou-324
Sample Nos. 279520-279588

William House of Wisconsin? now

County: Outagamie

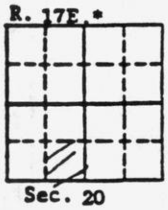
Well name Fox River Tractor Co.
Town of.. Grand Chute, Highways 10 & 41.
Owner.... Fox River Tractor Co.
Address.. Appleton, Wisconsin

Driller.. Goldbeck Well Drilling
Engineer.

Completed... 8/1/63
Field check.
Altitude.... 780'ETM
Use......... Factory
Static w. l. -- 55'
Spec. cap... -- 25

R. 17E.

T. 21 N.



Sec. 20

Quad. Appleton 7½'

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
18"	0	20'				14"	steel	+24"	47'				
14"	20'	100'				8"	steel	+24"	100'				
8"	100'	653'											

Grout: Kind	from	to
Neat cement	+24"	20'
Neat cement	+24"	100'

Samples from 0 to 640'
Date received: 1964
Examined by: J. M. Warren
Issued: 8/68
Date: 3/27/68

Formations: Drift, Prairie du Chien, Trempealeau, Tunnel City, Ironton, Galesville,

Remarks: Well tested for 3 hours at 50 gpm with 2 feet of drawdown. Driller reports total well depth as 632 feet. Bedrock (PdC) differs from reported bedrock in USGS County Report and WGS Geologic map. Interval between 50'-70' may be Platteville.

LOG OF WELL:

DRIFT		0-5	5		Cl,V lt bn,F srtg,calcus,vrbl hdns;tr st
		5-10	5		NO SAMPLE
		10-15	5		Cl,V lt bn,F srtg,calcus,vrbl hdns;ltl st,tr V fn snd/V fn gvl
		15-35	20		NO SAMPLES
		35-40	5		Cl,pl rd,P srtg,calcus,sft;mch st,ltl V fn/VC snd&V fn gvl,mstly dol
	50'	40-50	10		NO SAMPLES
PRAIRIE du CHIEN		50-70	20		Dol,lt gry mot yl gry,V fn,dns,tr fn;tr xln&dissem pyr&lim spks
		70-90	20		Dol, lt gry mot wh & gry, fn & V fn, dns, ltl sndy(fn/VC);tr xln &dissem pyr,mch fn/C snd & gn sh
		90-95	5		Dol,lt gry mot wh&gry,fn,dns,ltl M&V fn,tr C,tr sndy(fn&M);tr xln &dissem pyr
		95-100	5		Dol,V pl or,fn&V fn,dns,tr-ltl sndy(V fn/M);mch pl gn sh
		100-105	5		NO SAMPLE
		105-110	5		NO SAMPLE
		110-115	5		Dol,yl gry mot ol gry,lt gry&V pl or,fn&V fn,dns,tr M&C
		115-120	5		NO SAMPLE
		120-125	5		Dol,V pl or mot gry or,fn,dns,ltl V fn&M;ltl cht,hd P gn sh,xln pyr
		125-130	5		Dol,V pl or mot gry or,fn,dns,ltl V fn&M;hd gn sh,fn/VC snd,foss frags&V pl gry rd sh
		130-140	10		NO SAMPLES
		140-150	10		Dol,V pl gry or mot yl gry,fn,dns,ltl M&V fn,tr sug tex;tr pl rd sh
		150-170	20		NO SAMPLES
		170-175	5		Dol,V pl or,V fn,sft;tr fn&V fn snd
		175-180	5		NO SAMPLE
		180-185	5		Dol,V pl or,M&fn,mod dns,ltl sft,ltl V fn;tr sug tex;tr wh cht&gn sh

Appendix IV. (continued) Fox River Tractor Lithology Report (continued)

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY Log No. Ou-324
1815 University Avenue, Madison, Wisconsin 53706

Well name Fox River Tractor Company
Sample Nos. 279520 to 279588

		185-195	10		NO SAMPLES
		195-200	5		Ss,or pnk,M,rnd,P srtg,tr P lim-&dol-cem,mch fn&C,ltl VC&V fn:tr st
P		200-205	5		Dol,or pnk,V fn/M,sft,tr yl or glaucic dol:tr V fn/M snd,ltl or pnk sty sh
d		205-215	10		NO SAMPLES
u		215-220	5		Dol,yl gry mot gry or pnk,fn,mod dns,ltl M&V fn,tr sug tex;tr V fn/C snd&hd gn sh
C		220-230	10		NO SAMPLES
		230-235	5	G	Dol,rd or,M&fn,sft,ltl V fn,ltl sndy(fn&M),ltl mot gry rd;few ools
		235-240	5		Dol,rd or,M&fn,sft,ltl V fn,ltl sndy(V fn/M),ltl mot gry rd,few ools
	195	240-245	5	G	Dol,rd or mot rd,gry rd&V pl or,fn,sft,ltl M&V fn,ltl sndy(V fn/M)
		245-250	5		Dol,rd or mot rd,gry rd&V pl or,fn&V fn,sft;mchfn&V fn snd,tr M/VC
T		250-255	5		Dol,rd or mot gry rd,V fn,sft,sndy(V fn)&dns gry;mch V fn&fn snd
		255-265	10		NO SAMPLES
R		265-270	5	G	Dol,V pl or mot or pnk,V fn,mod dns,ltl sndy(V fn)glaucic;mch rd
	30	270-275	5	G	Dol,V pl or mot or pnk,V fn,mod dns,ltl bn mot pl gn sts
T		280-285	5	G	Ss,gry pnk,M,Sang,F srtg,tr G dol-cem,mch fn&C:ltl fn/C grnd glauc
		285-290	5	G	Ss,V pl or,M&fn,Sang,F srtg,tr V fn:tr glauc \lt rd dol&pl rd sts
		290-295	5	G	Ss,gry or pnk,fn,ang,F srtg,ltl M,tr V fn:tr glauc,dol,pl rd sts&gn sh
C		295-300	5		NO SAMPLE
	30	300-305	5	G	Ss,gry or pnk,fn,ang,F srtg,tr M&V fn:tr glauc,dol,pl rd sts&gn sh
		305-310	5		Ss,V lt gry,C,Srnd,F srtg,tr lt rd dol-cem,mch M,ltl fn&VC,tr V fn;
I		310-315	5		NO SAMPLE \tr gn sh,rd bn sts,glaucic dol&pyr
R		315-320	5		Ss,V lt gry,M,Srnd,F srtg,tr G lt rd dol-cem,mch C&fn,tr VC&V fn; tr glauc.
		320-330	10		NO SAMPLES
O		330-335	5		Ss,V lt gry,M,Srnd,F srtg,tr G lt rd dol-cem,mch C&fn,tr VC&V fn
		335-340	5		Dol,or pnk,lt rd&V pl or,fn,mod dns,sug tex,V sndy(fn/VC),V glaucic
N		340-345	5		NO SAMPLE \ (V fn/C):tr-ltl G pyr-cemtd ss
		345-350	5		Ss,V pl or,C,rnd,F srtg,tr-ltl G lt rd dol-cem,mch M,ltl fn&VC,tr V fn:tr gn sh&pyr-cem
	[illegible]	350-365	15	G	Ss,V lt gry,C,rnd,P srtg,tr G lt rd dol-cem... mch fn&C,tr VC&V fn:tr pyr-cem&glauc
		365-370	5		Ss,wh,M,rnd,P srtg,mch fn&C,tr V fn&VC:tr lim-cem
		370-375	5		NO SAMPLE
G		375-380	5		Ss,wh,M,rnd,P srtg,mch fn&C,tr V fn&VC:tr lim-cem
		380-385	5		Ss,V pl or,M&C,rnd,P srtg,ltl fn,tr VC&V fn:tr lim-cem&lt bn dol
A		385-395	10		NO SAMPLES
		395-400	5		Ss,pl or,M&fn,Srnd,F srtg,tr P lim-cem,tr C&V fn:tr pyr-cem
L		400-410	10		NO SAMPLES
		410-415	5		Ss,V pl or,M&fn,Srnd,P srtg,tr F lim-cem,ltl C,tr V fn:tr st&pyr-ce
E					
S		415-430	15		NO SAMPLES
		430-435	5		Ss,wh,M&C,rnd,F srtg,tr F lim-cem,ltl fn,tr VC&V fn:tr st
V		435-440	5		NO SAMPLE
I		440-450	10		Ss,pl or,M,rnd,P srtg,tr F lim-cem,mch fn&C,tr VC:tr st
		450-455	5		Ss,pl or,M,rnd,P srtg,mch fn&C,ltl V fn,tr VC:tr st,lim-&pyr-cem&bn dol
L		455-460	5		NO SAMPLE
		460-465	5		Ss,V pl gry or,M,rnd,P srtg,mch fn&C,ltl V fn,tr VC:tr st&lim-cem
L		465-475	10		NO SAMPLES
E		475-480	5		Ss,V pl or,C,rnd,P srtg,tr F lim-cem,mch M&VC,ltl fn,tr V fn:tr st
		480-495	15		NO SAMPLES
		495-500	5		Ss,V pl yl or,M&C,rnd,P srtg,tr F lim-cem,ltl fn,tr V fn&VC
		500-505	5		NO SAMPLE
		505-510	5		Ss,V pl yl or,M&fn,rnd,P srtg,tr F lim-cem,ltl C,tr V fn;tr st
		510-520	10		NO SAMPLES
		520-530	10		Ss,V pl yl or,M,rnd,P srtg,tr F lim-cem,ltl fn&C,tr V fn&VC
		530-540	10		Ss,gry or pnk,M,rnd,P srtg, ltl F-P lim-cem, mch fn&C,tr V fn&VC; tr st,pyr-&dol-cem
		540-550	10		Ss,V pl or,M,rnd,P srtg,tr F lim-cem,ltl fn&C,tr V fn&VC

Appendix IV. (continued) Fox River Tractor Lithology Report (continued)

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY **Log No.** Ou-324
1815 University Avenue, Madison, Wisconsin 53706

Well name Fox River Tractor Co.
Sample Nos. 279520 to 279588

GALES		550-565	15		NO SAMPLES
		565-580	15	∴	Ss,lt rd,M,rnd,P srtg,ltl P lt rd dol-cem,ltl fn&C;slgt tr st
		580-605	25		NO SAMPLES
		605-610	5	∴	Ss,pl or,M,rnd,P srtg,ltl F-P lim-cem,mch fn,ltl C;slgt tr st
		610-615	5		NO SAMPLE
		615-620	5	∴	Ss,V pl or,M&fn,rnd,F srtg,ltl F-P lim-cem,ltl C;slgt tr st
		620-625	5		NO SAMPLE
		625-630	5	∴	Ss,pl or,fn,Sang,F srtg,ltl F-P lim-cem,mch M,ltl C,tr V fn
		630-635	5	∴	Ss,pl or,M,rnd,F srtg,ltl F-P lim-cem,mch fn&C:tr or pnk sts
	275	635-640	5	∴	Ss,pl or,fn,Srnd,F srtg,ltl F-P lim-cem,mch M,ltl C,tr V fn

END OF WELL

Appendix IV. (continued) Donald Valence Well Construction Report

Well Construction Report For WISCONSIN UNIQUE WELL NUMBER AG140

State of Wisconsin
Department of Natural Resources
Private Water Supply — WS/2
Box 7921
Madison, WI 53707

Property Owner Donald VALENSE **Telephone Number** [redacted]

Mailing Address 4170 OAK RIDGE Rd.

City Winchester **State** **Zip Code**

County WINNEBAGO **County Well Location Permit No.** W **Well Completion Date** 4 26 90 (M M D D Y Y)

Well Constructor (Business Name) **License #** 6

Address

City **State** **Zip Code**

1. Location (Please type or print using a black pen.)

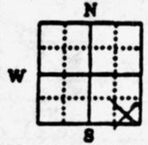
☒ Town ☐ City ☐ Village of CLAYTON **Fire # (if available)** 4170

Grid or Street Address or Road Name and Number (if available) OAKRIDGE Rd.

Subdivision Name **Lot #** **Block #**

Gov't Lot # ____ or SE ¼ of SE ¼ of Section 29 T 20 N; R 16 ☒ E ☐ W

2. Mark well location in correct 40-acre parcel of section.



3. Well Type ☒ New ☐ Replacement ☐ Reconstruction/Rehabilitation of well constructed in 19 ____.

Reason for new, reconstructed, replaced, or rehabilitated well? NEW HOME

☐ Drilled ☐ Driven Point ☐ Jetted ☐ Other ____

4. Well serves 1 # of homes and/or ____ (ex: barn, restaurant, church, school, industry, etc.)

High Capacity Well? ☐ Yes ☒ No

High Capacity Property? ☐ Yes ☒ No

5. Well Located on Highest Point of Property, Consistent with the General Layout and Surroundings? ☒ Yes ☐ No

Well Located in Floodplain? ☐ Yes ☒ No

Distance In Feet From Well To Nearest:

10' 2. Building Overhang
N/A 3. Septic or Holding Tank
N/A 4. Sewage Absorption Unit
____ 1. Landfill
____ 5. Nonconforming Pit
____ 6. Buried Home Heating Oil Tank
____ 7. Buried Petroleum Tank
____ 8. Shoreline/Swimming Pool
____ 9. Downspout/Yard Hydrant
____ 10. Privy
12 11. Foundation Drain to Clearwater
____ 12. Foundation Drain to Sewer
____ 13. Building Drain ☐ Cast Iron or Plastic ☐ Other
N/A 14. Building Sewer ☐ Gravity ☐ Pressure ☐ Cast Iron or Plastic ☐ Other
____ 15. Collector Sewer N/A - not in at time of
N/A 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 ☐ Gravity ☐ Pressure ☐ Cast Iron or Plastic ☐ Other
____ 23. Other Manure Storage ____
24. Other NR 112 Waste Source Drilling

6. Drillhole Dimensions

Dia. (in.)	From (ft.)	To (ft.)
9	surface	41
6	"	135

Method of constructing upper enlarged drillhole. (If applicable ✓ more than one.)

☒ 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? ☐ Yes ☐ No If no, explain ____
☐ 7. Other ____

7. Casing, Liner, Screen

Dia. (in.)	Material, Weight, Specification Mfg. & Method of Assembly	From (ft.)	To (ft.)
6	new black steel P.E. 18.97#, ASTM A53, Venezuela Pipe, Drive shoe, total pipe	surface	41 42

Dia. (in.)	screen type and material	From	To

8. Grout or Other Sealing Material

Method Dumping

Kind of Sealing Material	From (ft.)	To (ft.)	# Sacks Cement
Neat CEMENT	surface	41	4

9. Geology

Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
clay	surface	10
clay + stones	10	16
clay	16	18
HARDPAN + STONES	18	27
LIMESTONE	27	117
Shale + SANDSTONE	117	133
LIMESTONE	133	135
TOTAL DEPTH		135

10. Static Water Level 10 ft. below ground surface

11. Pump Test Pumping Level 63 ft. below surface Pumping at 10 GPM for 8 hours

12. Well Is: 12 in. ☒ Above ☐ Below Grade

Developed? ☒ Yes ☐ No

Disinfected? ☒ Yes ☐ No

Capped? ☒ Yes ☐ No

13. Were all unused, noncomplying, or unsafe wells properly filled with sealant? ☐ Yes ☒ No If no, explain None

14. Signature of Well Constructor **Date Signed**

Signature of Drill Rig Operator **Date Signed**

Make additional comments on reverse side about geology, etc.

nnoV

WELL CONSTRUCTION REPORT

WGNHS SUBSURFACE LAB DATA BASE
LITHOLOGY REPORT

03/16/1992

SEQ #	WELLID	TOP	BOTTOM	ROCKTYPE	COLOR	MODE	RANGE	NOTES	DESCRIPTION
1	710609	0.	5.	Clay	Red brown	--	--		Dolomitic.Much sand,silt,wh drilling mud.Tr grans.
2	710609	5.	10.	Clay	Red brown	--	--		Dolomitic.Much sand,silt.Few grans.Tr wh drilling mud.
3	710609	10.	15.	Clay & sand	Red brown	C/VC	Vfn/VC		Dolomitic.Much dolic sand,silt.Few grans.
4	710609	15.	20.	Gravel	Mxd gy bn	S peb	Gr/MP		Dolomite,chert,ss(dolic & pyrite cemtd),granite,gabbro,trap.Much sand,silt.Ltl rd bn clay.
5	710609	20.	25.	Gravel	Mxd gy bn	S peb	Gr/MP		Dolomite,chert,ss(dolic & pyrite cemtd),granite,gabbro,trap.Much sand.Ltl silt,rd bn clay.
6	710609	25.	30.	Gravel	Mxd gy bn	S peb	Gr/MP		Dolomite,chert,ss(dolic & pyrite cemtd),granite,gabbro,trap.Much sand,silt.Ltl rd bn clay.
7	710609	30.	35.	Dolomite	Gy brown	M	Fn/M	study break	Ltl uncon.Tr wh chert,floating qtz sand,fossil frags.
8	710609	35.	40.	Dolomite	Gy brown	M	Fn/M		Ltl uncon.Tr wh chert,floating qtz sand,fossil frags,gn sh.
9	710609	40.	45.	Dolomite	Gy brown	M	Fn/M		Many immature ooliths(some qtz snd cored).Much floating qtz sand.Tr mass glauc,gn sh,clear cal xtals,bn sh partings,cvd mat.
10	710609	45.	50.	Dolomite	Gy brown	M	Fn/M		Many immature ooliths.Ltl free qtz sand.Tr mass glauc,gn gy sh,clear cal xtals,bn sh partings.
11	710609	50.	55.	Dolomite	Gy brown	M	Fn/M		Tr immature ooliths,floating qtz sand,gn gy sh,clear cal xtals,bn sh partings.
12	710609	55.	60.	Dolomite	Gy brown	M	Fn/M		Tr floating qtz sand,gn gy sh,clear cal xtals,bn sh partings.
13	710609	60.	65.	Dolomite	Gy brown	M	Fn/M		Much floating qtz sand.Tr gn gy sh,clear cal xtals,bn sh partings,pyrite.
14	710609	65.	70.	Dolomite	Gy brown	M	Fn/M		Ltl floating qtz sand.Tr gn gy sh,clear cal xtals,bn sh partings.
15	710609	70.	80.	No Sample					
15	710609	80.	85.	Dolomite	Gy brown	M	Fn/M		Much floating/free qtz sand.Tr mass glauc,gn gy sh,clear cal xtals,bn sh partings.
16	710609	85.	90.	Dolomite	Dusky red	M	Fn/M		Much sh matrix(pur to rd bn interlayered w/ bl gy).Ltl conc floating/free qtz sand.Tr mass glauc,clear cal xtals,bn sh partings.
17	710609	90.	95.	Dolomite	Pl brown	M	Fn/M		Ltl floating/free qtz sand.Tr mass glauc,gn gy sh,pur hem sh,clear cal xtals,bn sh partings.
18	710609	95.	100.	Dolomite	Lt bn gy	M	Fn/M		Much floating/free qtz sand.Tr pyrite,clear cal xtals,bn sh partings.
19	710609	100.	105.	Dolomite	Lt gy to lt bn gy	M	Fn/M		Tr free qtz sand,fluorite,clear cal xtals,bn sh partings,gn gy sh,pl bn mica.

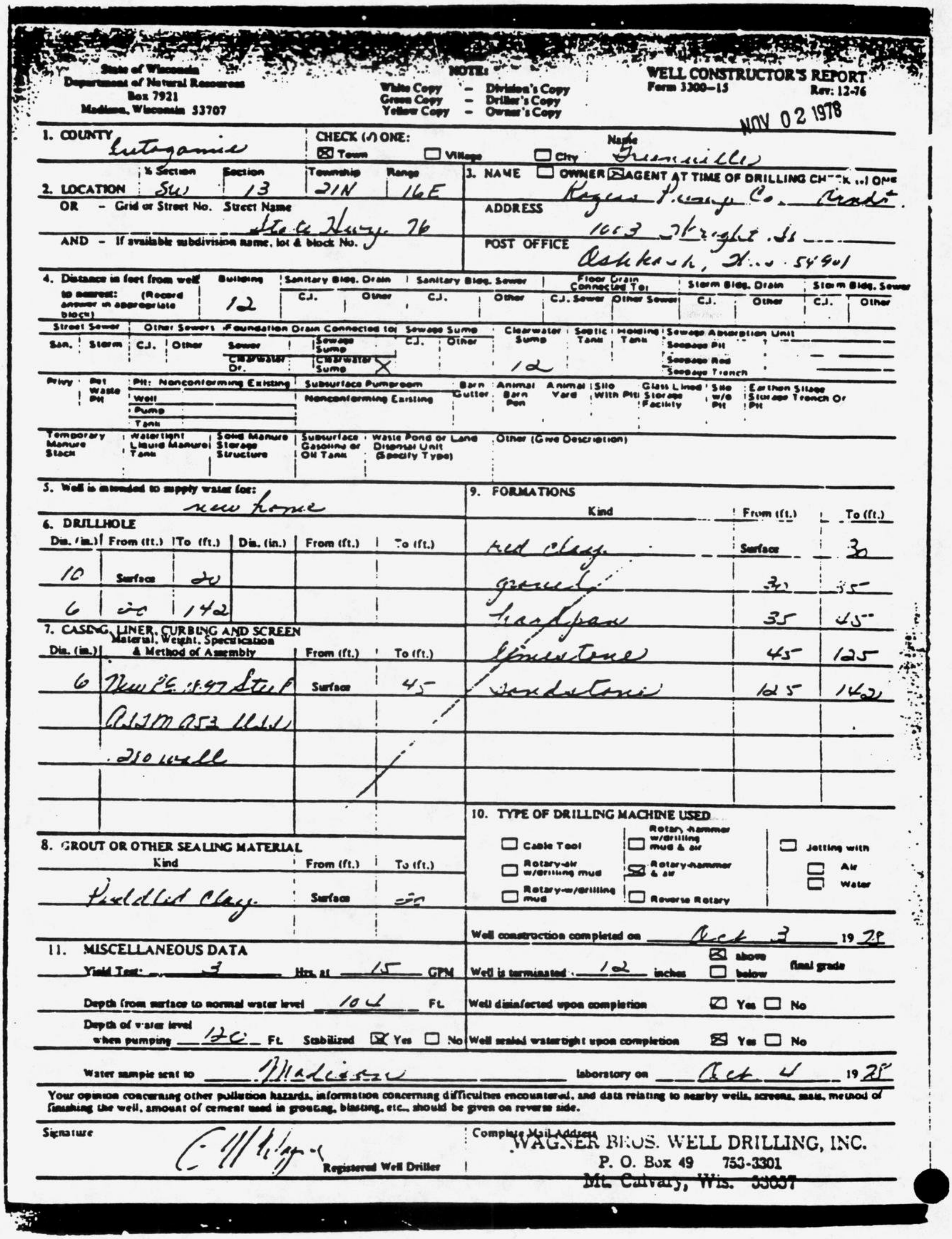
SEQ #	WELLID	TOP	BOTTOM	ROCKTYPE	COLOR	MODE	RANGE	NOTES	DESCRIPTION
20	710609	105.	110.	Dolomite	Lt gy to lt bn gy	M	Fn/M		Tr floating/free qtz sand,mass glauc,pyrite,clear cal xtals,bn sh partings,gn gy sh,pl bn mica.
21	710609	110.	115.	Dolomite	Lt bn gy	M	Fn/M		Ltl floating/free qtz sand(less coarse than above-Fn),yl lim staining.Tr mass glauc,clear cal xtals,bn sh partings,gn gy sh.
22	710609	115.	120.	Shale	Dk rd bn	--	--	Studybreak	Hematitic.Much dol(as above),qtz silt.Ltl pl gn sh.Tr pyrite,qtz sand.
23	710609	120.	125.	Chert	Yellow red & wh	--	--		Sample looks like silicified ss and/or sts.Much floating qtz silt/sand,wh G silcs cemtd ss.Tr pyrite,rd bn sh(as above).
24	710609	125.	130.	Chert	White	--	--		Most of the chert is drusy formed.Ltl clear drusy qtz,free qtz silt/sand.Tr wh G silcs cemtd ss,cvd mat.
25	710609	130.	135.	Chert & shale	White & dk rd bn	--	--		Chert:Most of the chert is drusy formed.Much VG silcs cemtd ss.Ltl clear drusy qtz,free qtz silt/sand.Tr pyrite,ooliths.Shale:Hematitic.Ltl gy sh.Tr silt/Vfn-glauc(esp w/ gy sh),mica,pyrite.

The pyrite occurrence is less than .1% in any one sample.

Kathleen Massie Ferch
3/16/92

APPENDIX V

Appendix V. Original Baumgart Well Construction Report



State of Wisconsin
Department of Natural Resources
Box 7921
Madison, Wisconsin 53707

NOTE:
White Copy - Division's Copy
Green Copy - Driller's Copy
Yellow Copy - Owner's Copy

WELL CONSTRUCTOR'S REPORT
Form 3300–15
Rev: 12-76

NOV 02 1978

1. COUNTY Outagamie
CHECK (✓) ONE: ☒ Town ☐ Village ☐ City Name Greenville

2. LOCATION ¼ Section SW Section 13 Township 21N Range 16E
OR - Grid or Street No. Street Name State Hwy. 76
AND - If available subdivision name, lot & block No.

3. NAME ☐ OWNER ☒ AGENT AT TIME OF DRILLING CHECK ONE
Rogers Pump Co. Agent
ADDRESS 1003 Wright St.
POST OFFICE Oshkosh, Wis. 54901

4. Distance in feet from well to nearest: (Record answer in appropriate block)

Building	Sanitary Bldg. Drain C.I.	Sanitary Bldg. Drain Other	Sanitary Bldg. Sewer C.I.	Sanitary Bldg. Sewer Other	Floor Drain Connected To: C.I. Sewer	Floor Drain Connected To: Other Sewer	Storm Bldg. Drain C.I.	Storm Bldg. Drain Other	Storm Bldg. Sewer C.I.	Storm Bldg. Sewer Other
12										

Street Sewer San.	Street Sewer Storm	Other Sewers C.I.	Other Sewers Other	Foundation Drain Connected to: Sewer	Foundation Drain Connected to: Clearwater Dr.	Sewage Sump	Clearwater Sump	Sewage Sump C.I.	Sewage Sump Other	Clearwater Sump	Septic Tank	Holding Tank	Sewage Absorption Unit: Seepage Pit / Seepage Bed / Seepage Trench
							X			12			

Privy | Pet Waste Pit | Pit: Nonconforming Existing: Well / Pump / Tank | Subsurface Pumproom Nonconforming Existing | Barn Gutter | Animal Barn Pen | Animal Yard | Silo With Pit | Glass Lined Storage Facility | Silo w/o Pit | Earthen Silage Storage Trench Or Pit

Temporary Manure Stack | Watertight Liquid Manure Tank | Solid Manure Storage Structure | Subsurface Gasoline or Oil Tank | Waste Pond or Land Disposal Unit (Specify Type) | Other (Give Description)

5. Well is intended to supply water for: new home

6. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
10	Surface	20			
6	20	142			

7. CASING, LINER, CURBING AND SCREEN

Dia. (in.)	Material, Weight, Specification & Method of Assembly	From (ft.)	To (ft.)
6	New PE 18.97 Steel ASTM A53 Weld .280 wall	Surface	45

8. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)
Puddled Clay	Surface	20

9. FORMATIONS

Kind	From (ft.)	To (ft.)
red clay	Surface	30
gravel	30	35
hardpan	35	45
limestone	45	125
sandstone	125	142

10. TYPE OF DRILLING MACHINE USED
☐ Cable Tool
☐ Rotary-air w/drilling mud
☐ Rotary-w/drilling mud
☐ Rotary-hammer w/drilling mud & air
☒ Rotary-hammer & air
☐ Reverse Rotary
☐ Jetting with ☐ Air ☐ Water

Well construction completed on Oct 3 1978
Well is terminated 12 inches ☒ above ☐ below final grade
Well disinfected upon completion ☑ Yes ☐ No
Well sealed watertight upon completion ☒ Yes ☐ No

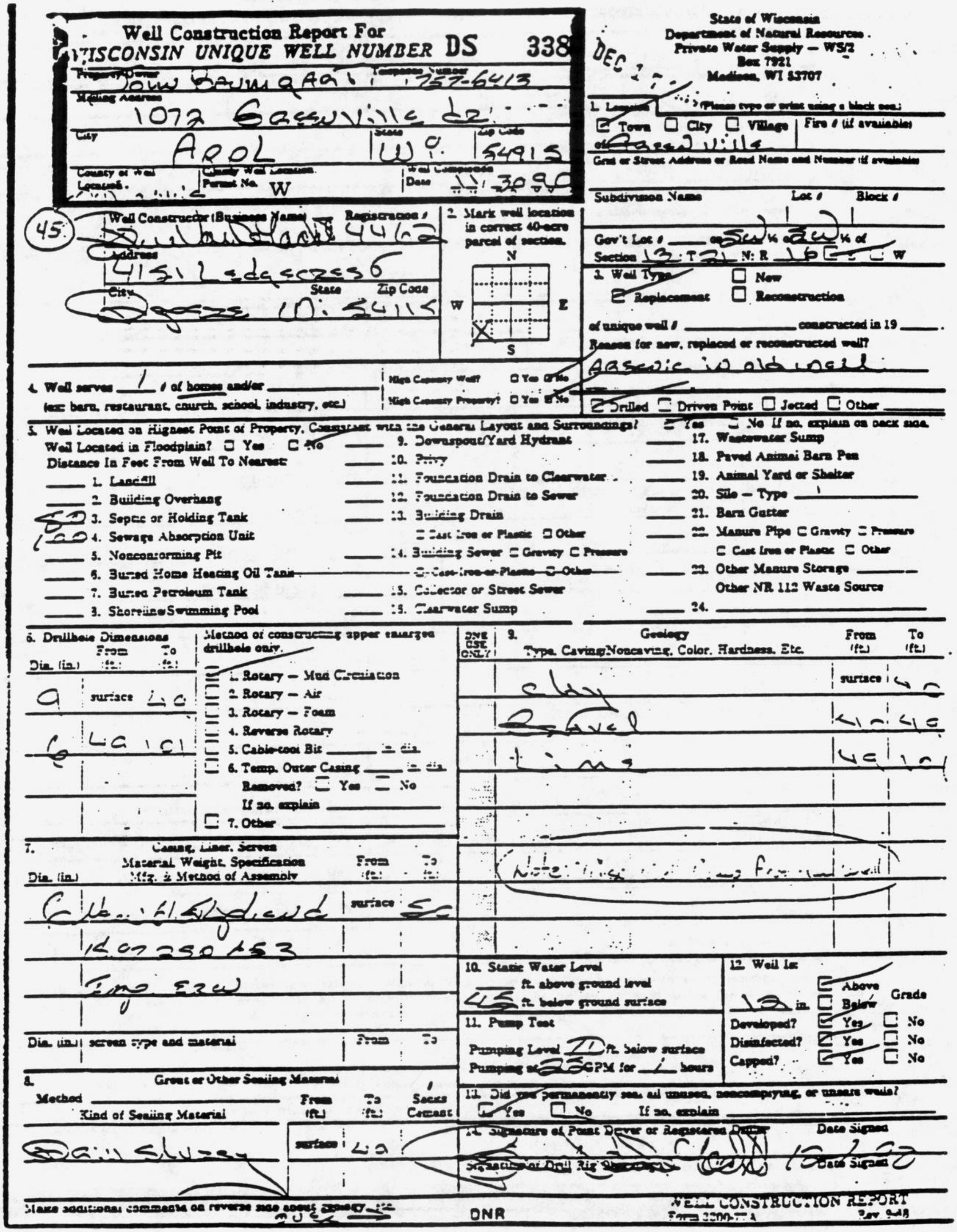
11. MISCELLANEOUS DATA
Yield Test: 3 Hrs. at 15 GPM
Depth from surface to normal water level 104 Ft.
Depth of water level when pumping 120 Ft. Stabilized ☒ Yes ☐ No
Water sample sent to Madison laboratory on Oct 4 1978

Your opinion concerning other pollution hazards, information concerning difficulties encountered, and data relating to nearby wells, screens, seals, method of finishing the well, amount of cement used in grouting, blasting, etc., should be given on reverse side.

Signature Registered Well Driller

Complete Mail Address
WAGNER BROS. WELL DRILLING, INC.
P. O. Box 49 753-3301
Mt. Calvary, Wis. 53057

Appendix V. (continued) New Baumgart Well Construction Report



Well Construction Report For
WISCONSIN UNIQUE WELL NUMBER DS 338

DEC 17

State of Wisconsin
Department of Natural Resources
Private Water Supply — WS/2
Box 7921
Madison, WI 53707

Property Owner: Don Baumgart
Telephone Number: 757-6413
Mailing Address: 1072 [illegible]ville Rd
City: AROL
State: Wi.
Zip Code: 54915
County of Well Location: [illegible]
County Well Location Permit No. W
Well Completion Date: 11-30-90

45

Well Constructor (Business Name): [illegible]
Registration #: 4462
Address: 4151 [illegible]
City: [illegible]
State: Wi.
Zip Code: 54115

2. Mark well location in correct 40-acre parcel of section.

N / W / E / S

1. Location (Please type or print using a black pen)
☑ Town ☐ City ☐ Village
of [illegible] Ville
Fire # (if available)
Grid or Street Address or Road Name and Number (if available)
Subdivision Name
Lot #
Block #
Gov't Lot # ______ or SW ¼ of SW ¼ of
Section 13; T 21 N; R 16 ☑ E ☐ W

3. Well Type ☐ New
☑ Replacement ☐ Reconstruction
of unique well # ______ constructed in 19 ______.
Reason for new, replaced or reconstructed well?
Arsenic in old well

4. Well serves 1 # of homes and/or ______
(ex: barn, restaurant, church, school, industry, etc.)

High Capacity Well? ☐ Yes ☑ No
High Capacity Property? ☐ Yes ☑ No

☑ Drilled ☐ Driven Point ☐ Jetted ☐ Other ______

5. Well Located on Highest Point of Property, Consistent with the General Layout and Surroundings? ☑ Yes ☐ No If no, explain on back side.
Well Located in Floodplain? ☐ Yes ☐ No
Distance In Feet From Well To Nearest:

______ 1. Landfill
______ 2. Building Overhang
50 3. Septic or Holding Tank
100 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 ☐ Cast Iron or Plastic ☐ Other
______ 14. Building Sewer ☐ Gravity ☐ Pressure ~~☐ Cast Iron or Plastic ☐ 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 ☐ Gravity ☐ Pressure ☐ Cast Iron or Plastic ☐ Other
______ 23. Other Manure Storage ______
Other NR 112 Waste Source
______ 24. ______

6. Drillhole Dimensions

Dia. (in.)	From (ft.)	To (ft.)
9	surface	40
6	40	101

Method of constructing upper enlarged drillhole only.
☑ 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? ☐ Yes ☐ No
If no, explain ______
☐ 7. Other ______

9. Geology

DNR USE ONLY	Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
	clay	surface	40
	Gravel	40	45
	Lime	45	101

(Note: [illegible] from [illegible] well)

7. Casing, Liner, Screen

Dia. (in.)	Material, Weight, Specification Mfg. & Method of Assembly	From (ft.)	To (ft.)
6	[illegible] K07250 153 Eng. ERW	surface	50

Dia. (in.) screen type and material From To

10. Static Water Level
______ ft. above ground level
45 ft. below ground surface

11. Pump Test
Pumping Level 70 ft. below surface
Pumping at 25 GPM for 1 hours

12. Well Is:
12 in. ☑ Above ☐ Below Grade
Developed? ☑ Yes ☐ No
Disinfected? ☑ Yes ☐ No
Capped? ☑ Yes ☐ No

8. Grout or Other Sealing Material
Method ______

Kind of Sealing Material	From (ft.)	To (ft.)	Sacks Cement
Drill Slurry	surface	40	

13. Did you permanently seal all unused, noncomplying, or unsafe wells? ☑ Yes ☐ No If no, explain ______

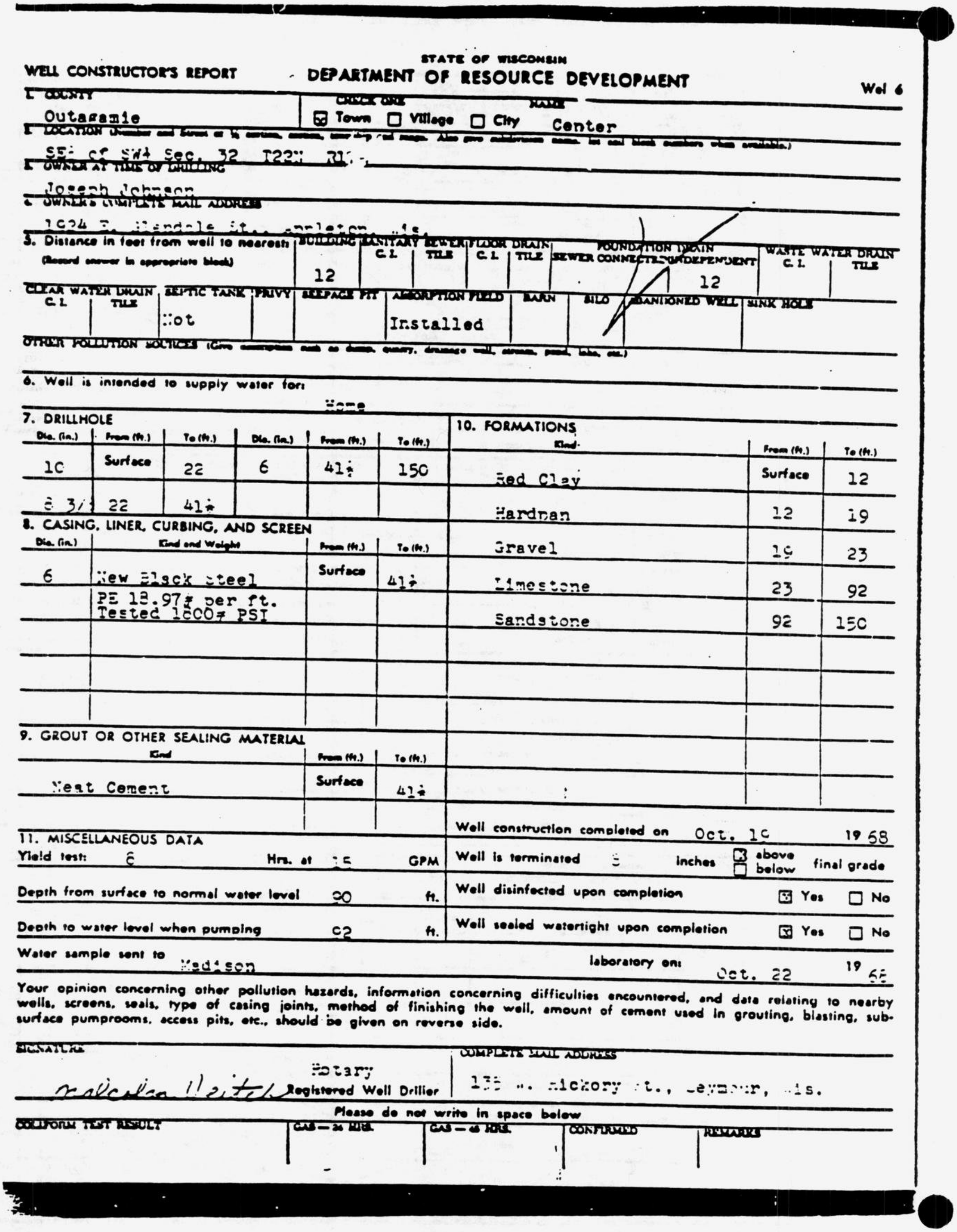
14. Signature of Pump Driver or Registered Driller: [illegible]
Date Signed: 12-1-90
Signature of Drill Rig Supervisor
Date Signed

Make additional comments on reverse side about geology, etc.

DNR

WELL CONSTRUCTION REPORT
Form 3300-77A Rev. 9-88

Appendix V. (continued) Original Voster Well Construction Report



WELL CONSTRUCTOR'S REPORT

STATE OF WISCONSIN

DEPARTMENT OF RESOURCE DEVELOPMENT

Wel 6

1. COUNTY Outagamie — CHECK ONE ☒ Town ☐ Village ☐ City — NAME Center
2. LOCATION (Number and Street or ¼ section, section, township and range. Also give subdivision name, lot and block numbers when available.) SE¼ of SW¼ Sec. 32 T22N R1
3. OWNER AT TIME OF DRILLING Joseph Johnson
4. OWNER'S COMPLETE MAIL ADDRESS 1624 E. Glendale St., Appleton, Wis.
5. Distance in feet from well to nearest: (Record answer in appropriate block)

BUILDING	SANITARY SEWER C.I.	SANITARY SEWER TILE	FLOOR DRAIN C.I.	FLOOR DRAIN TILE	FOUNDATION DRAIN SEWER CONNECTED	FOUNDATION DRAIN INDEPENDENT	WASTE WATER DRAIN C.I.	WASTE WATER DRAIN TILE
12						12		

CLEAR WATER DRAIN C.I.	CLEAR WATER DRAIN TILE	SEPTIC TANK	PRIVY	SEEPAGE PIT	ABSORPTION FIELD	BARN	SILO	ABANDONED WELL	SINK HOLE
		Not			Installed				

OTHER POLLUTION SOURCES (Give description such as dump, quarry, drainage well, stream, pond, lake, etc.)

6. Well is intended to supply water for: Home

7. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
10	Surface	22	6	41½	150
8 3/4	22	41½			

8. CASING, LINER, CURBING, AND SCREEN

Dia. (in.)	Kind and Weight	From (ft.)	To (ft.)
6	New Black Steel PE 18.97# per ft. Tested 1000# PSI	Surface	41½

9. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)
Neat Cement	Surface	41½

10. FORMATIONS

Kind	From (ft.)	To (ft.)
Red Clay	Surface	12
Hardpan	12	19
Gravel	19	23
Limestone	23	92
Sandstone	92	150

11. MISCELLANEOUS DATA

Yield test: 6 Hrs. at 15 GPM

Depth from surface to normal water level 90 ft.

Depth to water level when pumping 92 ft.

Water sample sent to Madison laboratory on: Oct. 22 1968

Well construction completed on Oct. 10 1968

Well is terminated 8 inches ☒ above ☐ below final grade

Well disinfected upon completion ☒ Yes ☐ No

Well sealed watertight upon completion ☒ Yes ☐ No

Your opinion concerning other pollution hazards, information concerning difficulties encountered, and data relating to nearby wells, screens, seals, type of casing joints, method of finishing the well, amount of cement used in grouting, blasting, sub-surface pumprooms, access pits, etc., should be given on reverse side.

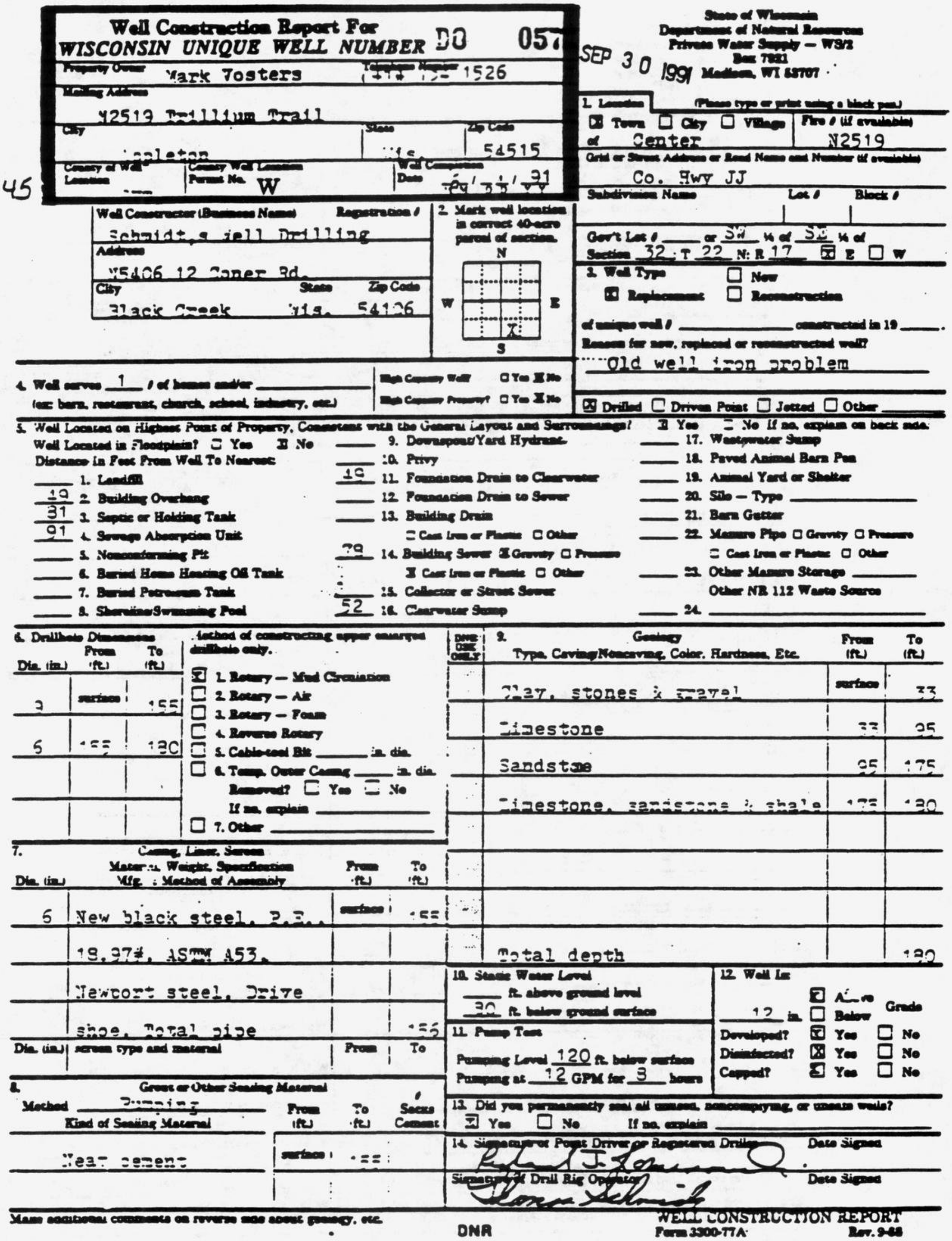
SIGNATURE Rotary Registered Well Driller

COMPLETE MAIL ADDRESS 135 W. Hickory St., Seymour, Wis.

Please do not write in space below

COLIFORM TEST RESULT	GAS — 24 HRS.	GAS — 48 HRS.	CONFIRMED	REMARKS

Appendix V. (continued) New Voster Well Construction Report



Well Construction Report For
WISCONSIN UNIQUE WELL NUMBER DO 057

SEP 30 1991

State of Wisconsin
Department of Natural Resources
Private Water Supply – WS/2
Box 7921
Madison, WI 53707

Property Owner: Mark Vosters
Telephone Number: [illegible] 1526
Mailing Address: N2519 Trillium Trail
City: Appleton
State: Wis.
Zip Code: 54515
County of Well Location: [illegible]
County Well Location Permit No. W
Well Completion Date: 6/25/91

45

Well Constructor (Business Name): Schmidt's Well Drilling
Registration #:
Address: N5406 12 Corner Rd.
City: Black Creek
State: Wis.
Zip Code: 54106

2. Mark well location in correct 40-acre parcel of section.

N / W / E / S: X

1. Location (Please type or print using a black pen.)
☒ Town ☐ City ☐ Village of Center
Fire # (if available): N2519
Grid or Street Address or Road Name and Number (if available): Co. Hwy JJ
Subdivision Name:
Lot #:
Block #:
Gov't Lot # ____ or SW ¼ of SE ¼ of Section 32; T 22 N; R 17 ☒ E ☐ W

3. Well Type ☐ New ☒ Replacement ☐ Reconstruction
of unique well # ____________ constructed in 19____.
Reason for new, replaced or reconstructed well? Old well iron problem

☒ Drilled ☐ Driven Point ☐ Jetted ☐ Other ______

4. Well serves 1 # of homes and/or ______________
(ex: barn, restaurant, church, school, industry, etc.)
High Capacity Well? ☐ Yes ☒ No
High Capacity Property? ☐ Yes ☒ No

5. Well Located on Highest Point of Property, Consistent with the General Layout and Surroundings? ☒ Yes ☐ No If no, explain on back side.
Well Located in Floodplain? ☐ Yes ☒ No
Distance in Feet From Well To Nearest:

____ 1. Landfill
19 2. Building Overhang
31 3. Septic or Holding Tank
91 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
19 11. Foundation Drain to Clearwater
____ 12. Foundation Drain to Sewer
____ 13. Building Drain
☐ Cast Iron or Plastic ☐ Other
29 14. Building Sewer ☒ Gravity ☐ Pressure
☒ Cast Iron or Plastic ☐ Other
____ 15. Collector or Street Sewer
52 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 ☐ Gravity ☐ Pressure
☐ Cast Iron or Plastic ☐ Other
____ 23. Other Manure Storage ______
Other NR 112 Waste Source
____ 24. ______________

6. Drillhole Dimensions

Dia. (in.)	From (ft.)	To (ft.)
9	surface	155
6	155	180

Method of constructing upper enlarged drillhole only.
☒ 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? ☐ Yes ☐ No
If no, explain ______________
☐ 7. Other ______________

7. Casing, Liner, Screen

Dia. (in.)	Material, Weight, Specification Mfg. & Method of Assembly	From (ft.)	To (ft.)
6	New black steel, P.E.,	surface	155
	18.97#, ASTM A53,		
	Newport steel, Drive		
	shoe. Total pipe		156

Dia. (in.)	screen type and material	From	To

8. Grout or Other Sealing Material
Method: Pumping

Kind of Sealing Material	From (ft.)	To (ft.)	# Sacks Cement
Neat cement	surface	155	

9. Geology

DNR USE ONLY	Type, Caving/Noncaving, Color, Hardness, Etc.	From (ft.)	To (ft.)
	Clay, stones & gravel	surface	33
	Limestone	33	95
	Sandstone	95	175
	Limestone, sandstone & shale	175	180
	Total depth		180

10. Static Water Level
____ ft. above ground level
30 ft. below ground surface

11. Pump Test
Pumping Level 120 ft. below surface
Pumping at 12 GPM for 3 hours

12. Well Is:
12 in. ☒ Above ☐ Below Grade
Developed? ☒ Yes ☐ No
Disinfected? ☒ Yes ☐ No
Capped? ☒ Yes ☐ No

13. Did you permanently seal all unused, noncomplying, or unsafe wells?
☒ Yes ☐ No If no, explain ______________

14. Signature of Point Driver or Registered Driller
Date Signed

Signature of Drill Rig Operator
Date Signed

Make additional comments on reverse side about geology, etc.

DNR

WELL CONSTRUCTION REPORT
Form 3300-77A Rev. 9-88

Appendix V. (continued) Original Olson Well Construction Report

State of Wisconsin
Department of Natural Resources
Private Water Supply
Box 7921
Madison, Wisconsin 53707

NOTE:
White Copy – Division's Copy
Green Copy – Driller's Copy
Yellow Copy – Owner's Copy

WELL CONSTRUCTOR'S REPORT
Form 3300–15 Rev. 2-79
NOV 2 6

COUNTY: Outagamie

CHECK (✓) ONE: ☑ Town ☐ Village ☐ City — Name: Osborn

2. LOCATION — ¼ Section or Gov't. Lot: SW — Section: 8 — Township, Range: 23N 18E

OR – Grid or Street No. — Street or Road Name: French

AND – If available subdivision name, lot & block No.

3. NAME ☑ OWNER ☐ AGENT AT TIME OF DRILLING CHECK (✓) ONE: Dick Olsen

ADDRESS: R.1

POST OFFICE: Seymour, Wi. — ZIP CODE

4. Distance in feet from well to nearest: (Record answer in appropriate block)

Building	Sanitary Bldg. Drain C.I.	Sanitary Bldg. Drain Other	Sanitary Bldg. Sewer C.I.	Sanitary Bldg. Sewer Other	Floor Drain Connected To: C.I. Sewer	Floor Drain Connected To: Other Sewer	Storm Bldg. Drain C.I.	Storm Bldg. Drain Other	Storm Bldg. Sewer C.I.	Storm Bldg. Sewer Other
12			60							

Street Sewer San.	Street Sewer Storm	Other Sewers C.I.	Other Sewers Other	Foundation Drain Connected to Sewer	Foundation Drain Connected to Clearwater Dr.	Foundation Drain Connected to Sewage Sump	Foundation Drain Connected to Clearwater Sump	Sewage Sump C.I.	Sewage Sump Other	Clearwater Sump	Septic Tank	Holding Tank	Sewage Absorption Unit: Seepage Pit	Seepage Bed	Seepage Trench	Manure Hopper or Retention or Pnuematic Tank
											70			30		

Privy	Pet Waste Pit	Nonconforming Existing: Well	Nonconforming Existing: Pump	Nonconforming Existing: Tank	Subsurface Pumproom	Nonconforming Existing	Barn Gutter	Animal Barn Pen	Animal Yard	Silo With Pit	Glass Lined Storage Facility	Silo w/o Pit	Earthen Silage Storage Trench Or Pit	Earthen Manure Basin

Temporary Manure Stack or Platform	Watertight Liquid Manure Tank or Basin	Manure Pressure Pipe	Subsurface Gasoline or Oil Tank	Waste Pond or Land Disposal Unit (Specify Type)	Manure Storage Basin	Concrete Floor Only	Concrete Floor and Partial Concrete Walls	Other (Describe)

5. Well is intended to supply water for: Home

6. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
9	Surface	41			
6	41	101			

7. CASING, LINER, CURBING AND SCREEN

Dia. (in.)	Material, Weight, Specification Mfg. & Method of Assembly	From (ft.)	To (ft.)
6	New Blk. Stl.	Surface	42
	Elec welded		
	ASTM A53 GR B		
	18.97 280		
	[illegible]		

8. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)
~~[illegible]~~ Grout	Surface	41

9. FORMATIONS

Kind	From (ft.)	To (ft.)
Clay	Surface	9
Limestone	9	60
Sandstone	60	101

10. TYPE OF DRILLING MACHINE USED

☐ Cable Tool
☐ Rotary-air w/drilling mud
☐ Rotary-w/drilling mud
☑ Rotary-hammer ~~w/drilling~~ mud & air
☐ Rotary-hammer & air
☐ Reverse Rotary
☐ Jetting with ☐ Air ☐ Water

Well construction completed on 11-19 84

Well is terminated 12 inches ☑ ~~above~~ ☐ below final grade

Well disinfected upon completion ☑ Yes ☐ No

Well sealed watertight upon completion ☑ Yes ☐ No

11. MISCELLANEOUS DATA

Yield Test: 2 Hrs. at 30 GPM

Depth from surface to normal water level 40 Ft.

Depth of water level when pumping 60 Ft. Stabilized ☑ Yes ☐ No

Water sample sent to Madison laboratory on 12-6 84

Your opinion concerning other pollution hazards, information concerning difficulties encountered, and data relating to nearby wells, screens, seals, method of finishing the well, amount of cement used in grouting, blasting, etc., should be given on reverse side.

Signature: Bill Van De Yacht — Registered Well Driller

Business Name and Complete Mailing Address:
Van De Yacht Bros. Well Drilling
3383 Oak Forest Drive
Green Bay, WI 54303

Appendix V. (continued) Olson Lithology Report

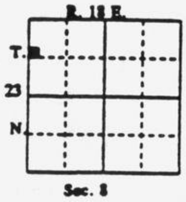
Wisconsin Geological and Natural History Survey
3817 Mineral Point Road, Madison, WI 53705

Geologic Log No: OU-623

SiteName: Dick and Sue Olson Well
Owner: Dick and Sue Olson
Address: N6808 French Road
Seymour, WI 54165
Driller(s): Bill Van de Yacht 10/1992
Bill Van de Yacht 11/14/1984
Engineer:
Location: SW,SW,NW,NW
Sec. 8, T23N, R18E
Topo Name: Freedom
Sample Nos: X28

County: OUTAGAMIE
Completed: 10/1992
Field Check:

Elevation: 855'
Well Use: Potable
Static Level: 40'



Pump Test:

Pumped at 30 GPM for 2 hrs. with 20 ft. of drawdown.
Specific Cap: 2 GPM/ft.

Samples Rec'd
5/10/92 110' to 300'

Studied By:
Kathleen M. Massie-Ferch 110' to 300'

Formations:
Kewaunee Formation, Sinnipee Group, Tonti Member, Readstown Member
St. Lawrence Formation, Tunnel City Group

Log Comments:

Published:

Drill Hole Dimentions

Diameter	From	To
9"	0'	41'
6"	41'	101'

Drilling Method

Method	From	To
Rotary - Mud Circulation	0'	300'

Grout

Type	From	To
Grout	0'	41'

Open Interval Characteristics

Diameter	From	To	OpeningType
6"	42'	300'	Open Hole

Casing & Liner Information

Diameter	From	To	Casing	Weight
6"	+1'	42'	Steel	18.97 lbs/ft

	Depths	Graphic	RockType Mode	Color Range	Miscellaneous Characteristics
KEW FM 9'	0 0		No Sample		Driller reports Clay.
SINNIPEE GROUP 41'	9.0 50.0		No Sample		Driller reports Limestone.
TONIT MEMBER	50.0 110.0		No Sample		Driller reports Sandstone.

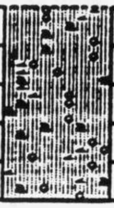
Appendix V. (continued) Olson Lithology Report (continued)

Geologic Log No: OU-623

		50.0 110.0	No Sample		Entry continued from last page. (Same sample)
TONTI MEMBER		110.0 115.0	Sandstone M	Light grey Vfn/VC	Rnd to wrnd.Ltl G dk bn silcs cem.Much frosting.Tr G pyrite cem,mafic incl,qtz silt,rust.
		115.0 120.0	Sandstone M	Light grey Vfn/VC	Rnd to wrnd.Ltl G dk bn to clear silcs cem.Much frosting.Tr G pyrite cem,mafic incl,qtz silt,rust.
		120.0 125.0	Sandstone Fn/M	Light grey Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		125.0 130.0	Sandstone M/C	Light grey Vfn/VC	Rnd to wrnd.Ltl G dk bn to clear silcs cem.Tr G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		130.0 135.0	Sandstone M/C	Light grey Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		135.0 140.0	Sandstone M/C	Pink Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		140.0 145.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		145.0 150.0	Sandstone M	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		150.0 155.0	Sandstone M	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		155.0 160.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		160.0 165.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		165.0 170.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Ltl G dk bn to clear silcs cem.Tr G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		170.0 175.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		175.0 180.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,wh silcs sh,rust.Much frosting.
		180.0 185.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Tr G dk bn to clear silcs cem,G pyrite cem,mafic incl,qtz silt,rust.Much frosting.Ltl wh silcs sh.
	40'	185.0 190.0	Sandstone M/C	V pl bn Vfn/VC	Rnd to wrnd.Ltl G silcs cem,rust.Tr G pyrite cem,mafic incl,qtz silt,rd bn staining,wh silcs sh.Much frosting.
READSTOWN MEMBER		190.0 195.0	Shale –	Dk rd bn & yl orcar –	Siliceous.Both colors of shales are thinly interlayered.Much free qtz sand/ss.Ltl qtz silt.Tr wh sh,rust.
		195.0 200.0	Sandstone M/C	Rd gy & orange Vfn/VC	Subrnd to rnd.Much VG silcs cem(almost a chert, color varies from org to pk to wh & rd bn).frstg.Ltl silcs sh(ss).Tr G pyrite cem,gn gy sh,mfc incl,qtz silt,wh sndy chert,rust.
		200.0 205.0	Sandstone M/C	Rd bn to dk rd bn Vfn/VC	Subang to rnd.Much VG silcs cem(chert-like).frosting.Ltl rd bn hemtc sh.Tr G hemtc cem,G pyrite cem,gn gy sh,mafic incl,qtz silt,wh sandy chert,rust.
		205.0 210.0	Sandstone M/C	Rd bn,or & dk rd bn Vfn/VC	Subang to rnd.Mch VG silcs cem(almost a cht, color varies from org to pk to wh & rd bn).frstg. Ltl rd bn hemtc sh.Few sec qtz grw.Tr G pyrite cem,mfc incl,qtz silt,wh sndy chert,rust.
		210.0 215.0	Shale & ss M/C	Rd bn,or & dk rd bn Vfn/VC	Sh:Rd bn & yl orcher.Siliceous.Hematitic.Sandy.Ss:Subrnd to rnd.Much VG silcs cem(almost a chert as above).frosting.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,rust.
		215.0 220.0	Shale & ss M/C	Rd bn,or & dk rd bn Vfn/VC	Sh:Rd bn & yl orcher.Siliceous.Hematitic.Sandy.Ss:Subrnd to rnd.Much VG silcs cem(almost a chert as above).frosting.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,rust.
		220.0 225.0	Sandstone M/C	Pk gy & dk rd bn Vfn/VC	Subrnd to rnd.Much VG silcs cem(almost a chert as above),frosting.Ltl dk rd bn hemtc sh.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,gn gy sh,rust.
		225.0 230.0	Sandstone M/C	Pk gy & dk rd bn Vfn/VC	Subrnd to rnd.Much G silcs cem(some chert-like).frosting.Ltl dk rd bn hemtc sh.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,yl orcher sh,rust.
		230.0 235.0	Shale & ss M/C	Dk rd bn & pk gy Vfn/VC	Sh:Hematitic.Ltl yl orcar sh(interbedded),sand.Ss:Subrnd to rnd.Much G silcs cem(tr chert-like).frosting.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,rust.
		235.0 240.0	Sandstone M/C	Pk gy & dk rd bn Vfn/VC	Subrnd to rnd.Much G silcs cem(some chert-like).frosting.Ltl dk rd bn hemtc sh.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,gn gy sh,yl orcher sh,rust.
		240.0 245.0	Sandstone M	Dark red Vfn/VC	Subrnd to rnd.Much G to VG silcs cem(some chert-like).frosting.Ltl dk rd bn hemtc sh.Few sec qtz growths.Tr G pyrite cem,mafic incl,qtz silt,wh sandy chert,gn gy sh,yl orcher sh,rust.
		245.0 250.0	Sandstone M/C	Red Vfn/VC	Subrnd to rnd.Ltl G to VG silcs cem(some cht-like).Much frstg.Few wh oolites(silicified dol. qtz snd cored, M/C).sec qtz grw.Tr pyr,mfc incl,qtz silt,wh chert,dk rd bn sh,yl orcher sh,rust.
		250.0 255.0	Sandstone M/C	Lt rd bn Vfn/VC	Subrnd to rnd.Ltl G to VG silcs cem(some chert-like).Much frosting.Few sec qtz growths.Tr pyrite,mafic incl,qtz silt,wh chert,dk rd bn sh,yl orcher sh,rust.
	70'	255.0 260.0	Sandstone Fn/M	Red bn & rd & wh Vfn/VC	Subang to rnd.Much G to VG silcs cem(some chert-like).frosting.Few sec qtz growths.Tr pyrite,mafic incl,qtz silt,wh chert,dk rd bn sh,yl orcher sh,wh sericite,mica,rust.
		260.0 265.0	Siltstone Silt/Vfn	Dirty or yl bn silt/Fn	Ang.Much G to VG silcs cem(some chert-like),frosting,qtz silt,rnd qtz sand(M/VC).Ltl dk rd bn sh,yl orcher sh.Tr silt/Vfn-glauc,pyrite,mafic sand,mica,rust.
		265.0 270.0	Siltstone Silt/Vfn	Dirty or yl bn silt/Fn	Ang.Much G to VG silcs to dolic cem(some cht-like),frstg,qtz silt,rnd qtz sand(M/C).Ltl dk rd bn sh,yl orcher sh.Tr silt/Vfn-glauc,pyrite,mfc snd,mica,dk gn gy sh(intertyrd w/ rd bn),rust.
	15'	270.0 275.0	Sandstone Vfn/Fn	Dirty or rd bn Vfn/C	Ang.Much G to VG silcs to dolic cem.frosting,qtz silt,rnd qtz sand(M/C).Ltl dk rd bn sh.silt/Fn-glauc.Tr yl orchr sh,pyrite,mafic sand,mica,dk gn gy sh(interlayered w/ rd bn),rust.

Appendix V. (continued) Olson Lithology Report (continued)

Geologic Log No: OU-623

TUNNEL CITY 25'	275.0 280.0		Sandstone Fn/M	Red brown VFn/VC	Red.Much G dolic cem,frosting,sl bn hemic sh,Fn/M-glauc,frosting.Tr qtz silt,wh fossil frags,yl ocular sh,pyrite,mafic sand,rust.
	280.0 285.0		Sandstone M	Red bn to dirty bn VFn/VC	Red to wvrd.Much G dolic cem,frosting,sl bn hemic sh,Fn/M-glauc,frosting.Ltl yl clay(wea glauc).Tr qtz silt,wh fossil frags,yl ocular sh,pyrite,rust.
	285.0 290.0		Sandstone Fn/M	Red brown VFn/VC	Red to wvrd.Much G dolic cem,frosting,sl bn hemic sh,Fn/C-glauc,frosting.Tr G sl spec hemic cem,yl clay(wea glauc),qtz silt,wh fossil frags,wh sh,gy sh,pyrite,rust.
	290.0 295.0		Sandstone M	Red brown VFn/VC	Red to wvrd.Much G dolic cem,frosting,sl bn hemic sh,Fn/C-glauc,frosting.Ltl wh sh.Tr G sl spec hemic cem,yl clay(wea glauc),qtz silt,wh fossil frags,mica,pyrite,rust.
	295.0 300.0		Sandstone M	Red brown VFn/VC	Red to wvrd.Much G dolic cem,frosting,Fn/C-glauc,frosting.Ltl sl bn hemic sh,wh sh.Tr G sl spec hemic cem,yl clay(wea glauc),qtz silt,wh fossil frags,mica,pyrite,rust.

End Of Log