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TJOSTEM, J. L., J. YOUNG, C. HOILIEN, AND R. ELSON IVERSON (Luther College, Decorah, Ia.) Bacterial and Nitrate Contamination of Well Water in Northeast Iowa. Proc. Iowa Acad. Sci. 84 (1):14-22, 1977.
Two hundred wells in the northeastern Iowa counties of Winneshiek and Allamakee were analyzed for nitrate concentration and coliform bacteria. The degree of well water contamination was found to correlate with aquifer tapped, type of well construction, and proximity to barnyards. Wells which terminated in the Galena Limestone aquifer usually showed evidences of surface pollution. Deeper wells which terminated in St. Peter Sandstone were found to produce consistently good water when cased into the sandstone. However, the water quality from a group of St. Peter Sandstone wells in which the overlying limestone was not cased out was not better than that in the Galena wells. Nitrates and coliform bacteria were tested periodically during the calendar year 1973 and summer 1974, in a group of seven wells. The water in the two deeply cased wells from this group consistently tested safe for drinking. The other five wells in which the overlying limestone was not cased out showed fluctuating nitrate levels 10− to 200− fold greater than the deeply cased wells and exhibited intermittant coliform contamination. These data are interpreted as evidence that surface contamination enters the fractured and cavernous Galena Limestone and is drawn into wells in response to pumping. This condition also occurs in deeper wells finished in the St. Peter Sandstone in which the Galena interval is left uncased. It indicates that when the wells are idle the water from the Galena, having a higher static head than the water from the St. Peter, probably moves down-hole into the St. Peter and contaminates the sandstone in that vicinity. This study supports a recommendation that new wells drilled through the upper cavernous limestone to deeper aquifers should be cased from the surface into the top of the St. Peter Sandstone with the pipe grouted in place with cement for its full length. This will protect the sandstone from contamination and insure high quality well water. Old wells extending to the St. Peter Sandstone that are to be abondoned should be properly plugged.
INDEX DESCRIPTORS: Groundwater contamination; Well water contamination.

Unsanitary and nitrate contaminated wells constitute a health hazard to humans, an economic liability to farmers and a threat to the vast ground water resource of our state. The need to protect and manage our ground water has been previously voiced. Hershey (1970) stressed the need for more chemical analysis of ground water, better well construction, more test drilling and a more precise geologic study of the ground water reservoir locations. Mack (1971) has compiled a summary of literature concerning the importance of ground water management. The Presidential Advisory Committee on water resources policy recommended that regulations relating to ground water be a matter of state concern. The committee suggested that the state give serious consideration to the enactment of appropriate legislation regarding ownership, right to use, purpose of use, and place of use of ground water. Lewicke (1972) urged the adoption of a national ground water policy.

In recent years water management has been mainly directed toward surface water; however, to neglect the management of our ground water is to run the risk of creating a health hazard for generations to come. If ground water nitrate concentrations are higher than 50mg/1, a potential health hazard exists for domestic animals and human infants (U.S. Public Health Service, 1962). Nitrate is reduced by intestinal bacteria to form nitrite and when combined with oxyhemoglobin, the blood forms methemoglobin. This globin decreases the oxygen carrying capacity of the blood and may produce the syndrome known as methemoglobinemia resulting in asphyxia and possible death. For this reason the Public Health Service Standards suggest that a limit of 45 mg/1 nitrate should not be exceeded for drinking water. Numerous instances due to nitrate toxicity from well water are reported (Bosch, et al., 1950; Carlson, et al., 1970; Comly, 1945; Donahue, 1949; Gelperin, et. al., 1971).

Particular concern for the pollution in ground water was aroused in September of 1972 in Winneshiek County. On Sept. 25 and 26, a total of 6.8 inches of rain was recorded at the Decorah radio station. Complaints of "muddy well water" were voiced by many area residents during the week that followed. A check of several wells showing silt in the water indicated extremely high counts of coliform bacteria. The murkiness but not the bacteria in the water of affected wells cleared up within one week. We super chlorinated one contaminated well with two gallons of Hilex and tested daily for coliform bacteria thereafter until the coliform bacteria returned. Coliform bacteria reappeared in the well water on the fourth day. This well was tested repeatedly for the presence of coliform bacteria the remainder of 1972. Each test showed the presence of coliforms but the level of contamination slowly dropped. Finally in March of 1973 the coliform bacteria disappeared from that well.

To understand and treat water supply problems such as these, the type and arrangement of geological formations which underlie the area must be considered. The geologic history of northeastern Iowa included the deposition of numerous sedimentary rock formations such as limestones, sandstones, and shales in the marine environments of the Ordovician and Cambrian periods. Younger sediments were deposited on top of these units but were later eroded away leaving the Ordovician and Cambrian strata as the bedrock over most of this area. The thick mantle of Pleistocene glacial clay which covers most of Iowa is thin to practically absent in the "Driftless Area" of Allamakee and eastern Winneshiek counties. Thus in much of this area the bedrock is unprotected except for a thin cover of soil and geest.

The sedimentary rocks are ideal groundwater reservoirs because of the permeability of the sandstones and large openings in the creviced and cavernous limestones and dolostones. Large quantities of water are held in storage in these formations. Shale, which is dense and insoluble in ground water, serves as an aquitard, confining the movement of water in the more porous aquifers. The closely packed sand grains in the sandstones have a natural filtering effect to remove minute particulate matter from the water but the carbonate formations do not possess this characteristics and the water in them is easily contaminated by surface infiltration. Limestone consists mainly of calcium carbonate and is soluble in ground water containing carbon dioxide in solution. Dolomite, a calcium magnesium carbonate is also soluble in ground water but to a lesser extent than limestone. Water in these rocks is stored mainly in solution cavities which form along bedding planes and in vertical fractures connecting the cavities. An excellent example of such a solution system is Cold Water Cave in Winneshiek County.

It is readily seen in traversing such a cave that there is no effective filtration of water in soluble limestone. The cave also serves to illustrate the distance that contaminated water can move through limestone aquifers. The sinkholes of Northeast lowa are also evidence that

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caverns have developed near the ground surface. Crevices and solution channels of varying sizes have been encountered by well drillers in northeastern Iowa wells that penetrate the limestone and dolomite formations.

METHODS

In order to compare types of well construction, the drilling logs of three well drilling firms were examined. Fifty wells which passed through one or both limestone layers and terminated in the St. Peter Sandstone were selected as a study representative of deep wells. We divided the group into 25 wells with steel casing through the Galena Limestone into the St. Peter aquifer, and 25 wells cased only to the top of the Galena Limestone.

A group of 50 wells representing the shallow wells which terminated in the Galena Limestone were compared with the former group of 50 St. Peter wells. Since the Galena wells were older, drilling logs were seldom complete or available.

Information was collected on the history of the water quality, age and depth of well, type of construction, and proximity to probable source of pollution. The surface elevation at the site of the well head was obtained with an altimeter. Elevation data was used in the interpretation of drilling logs. Data secured by interview with the owner or user of each well were tabulated.

Each water sample was collected in a new sterile 6 oz. bottle. Each sample collection was taken from a flame sterilized faucet which had been run for three minutes prior to sample collection.

The concentration of nitrate in water samples was determined by the phenoldisulfonic acid method in accordance with the Standard Methods for Examination of Water and Waste Water (American Public Health Association, 1971).

The number of total coliform fecal coliform and fecal streptococci bacteria were determined by the membrane filter technique and cultured as described in Standard Methods using Millipore and Gelman filter membranes.

Fecal coliform and fecal streptococci were also determined by the membrane filter technique in wells which tested high in total coliform. A characterization for the presence of *Salmonella* was carried out on water samples from badly polluted wells. Samples of varying size from 100 ml to 10 liters were collected on membrane filters. Enrichment was accomplished on tetrathionate. Brilliant green and XLD agar plates were streaked from the tetrathionate enrichment broth. Suspect colonies on the agar plates were innoculated into BHI broth for use in the innoculation of the Inolex multi-test system.

RESULTS

The Role of Aquifer and Casing in Well Water Quality

Figure 1, which is included as an aid to the interpretation of the data, depicts the movement of contaminated water through limestone and dolomite formations. Contamination of a sandstone aquifer by a well which is not cased through the limestone is also shown. The sources of contamination illustrated include: a sinkhole, a sewer system leaching pit, and a barnyard. The well at the right in the figure is cased to the sandstone and shown to be free of contamination.

Table 1 summarizes nitrate and coliform data collected on 100 wells which enter or pass through Galena Limestone in Winneshiek County. These data illustrate the differences in water quality of the St. Peter Sandstone and the Galena Limestone. These data also illustrate that wells which are drilled through the Galena Limestone into the underlying sandstone must be cased through the limestone if water free from surface contamination is to be obtained. Nitrate values for the group of 25 wells cased through limestone to sandstone (first column in

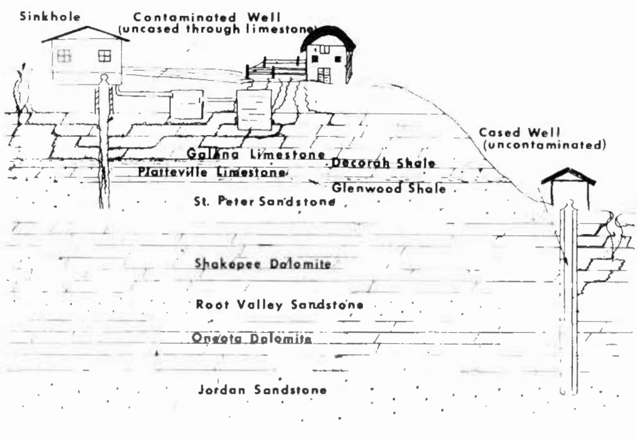


Figure 1. *Movement of contaminated water through limestone and dolomite.*

Table 1) averaged less than 2 mg/l and 22 of the group of 25 wells showed no coliform bacteria. The remaining three contained 1, 2, and 3 coliform/100 ml respectively. Since only a single test was made on each well, the possibility cannot be excluded that this slight contamination may have been introduced during sampling. The group of 25 wells which also terminated in the St. Peter Sandstone but differed from the former in that they were not cased through the limestone aquifer contained an average nitrate concentration of 28.9 mg/l. This value is 15 times higher than that for the group of wells cased through the limestone. Also 15 of the 25 wells in this latter group were contaminated with coliform bacteria. Eight wells of this group contained more than 8 coliforms/100 ml. The third group of wells summarized in Table 1 terminate in Galena Limestone. The average nitrate concentration for this group was 23.9 mg/l; 32 wells, or 64 per cent, contained coliform bacteria.

Table 1. *A comparison of nitrate and coliform bacterial contamination of the Galena Limestone aquifer with that of the St. Peter Sandstone aquifer. Contamination introduced into the St. Peter Sandstone through inadequately cased wells is also illustrated.*

	Wells terminating in St. Peter Sandstone, (Galena Limestone cased out)	**Wells terminating in St. Peter Sandstone, (Galena Limestone *not* cased out)**	**Wells terminating in Galena Limestone**
Number of wells sampled	25	25	50
Range of well depths in feet	230-560	230-407	20-170
Average depth in feet	355	306	100
Range of nitrate (NO_3) concentration in mg/l.	0.7-12	0.9-140	0.3-154
Average nitrate (NO_3) concentration in mg/l.	1.7	28.9	23.9
Number of wells contaminated with 1 or more coliforms/100ml.	3	15	32
Number of wells contaminated with 8 or more coliforms/100 ml.	0	8	21

Ten wells which terminated in the Root Valley or Oneota Formations were tested. Observe the geologic strata in Figure 1 for location of Root

Valley and Oneota Formations in relationship to the other rock units. The nitrate values for this group ranged from 10 to 60 mg/l and the average was 21 mg/l. Five of the 10 wells contained coliform bacteria. Four wells which terminated in the Jordan Sandstone were tested. The nitrate concentration in all four wells was found to be 7.5 mg/l. This value is higher than that for the group of wells cased to St. Peter Sandstone. Increased nitrate is caused by contamination. Note that in Figure 1 the Jordan aquifer well is not protected by an overlying shale as are most St. Peter wells. Thus nitrate from surface pollution eventually could work down to the Jordan through the Prairie du Chein especially if the well was pumped heavily. The four Jordan wells were found to be free from coliform contamination.

The nitrate concentration and coliform contamination was tested in 147 wells in Winneshiek County. With respect to nitrate concentration, 15 wells or 10.2% exceeded the 45 mg/l limit. Four of the wells found to be high in nitrate, or 2.7% of the total 147, were also contaminated with coliform bacteria. Therefore, 2.7% of the wells tested unsatisfactory with respect to both nitrate concentration and coliform bacteria. Seventy-four wells or 50.3% of the 147 were found to contain coliform bacteria. Thirty-four of 23.1% of the 147 contained a level of contamination greater than 8 coliforms/100 ml. Altogether 85 of 147 wells tested (57.8%) were found to be unsatisfactory either with respect to nitrate concentration, coliform bacteria, or both. Since random selection was not used in choosing wells for this study these data are not intended as an accurate assessment of the number of polluted wells in Winneshiek County.

Fifty three wells in Allamakee County displayed a similar picture. Seven wells or 13.2% exceeded the 45 mg/l limit for nitrate. All seven wells found to be high in nitrate were also found to be contaminated with coliform bacteria. Twenty eight or 52.8% of the wells tested in Allamakee county were found to contain coliform bacteria. Thirteen or 24.5% contained a level of contamination greater than 8 coliform/100 mls.

The selection of study wells was made by identifying deeply cased wells from well drillers logs. For purposes of comparing types of well construction the deeply cased wells and nearby uncased wells were sampled. Prior to 1965, wells were seldomly cased deeply. Therefore our study wells tend to cluster in localities where poor quality water had recently necessitated the drilling of a new well. For this reason a random sampling would probably show a lower percentage of polluted wells.

Contamination in Springs

A total of nine springs were tested for nitrate and coliform bacteria. Seven were from the Galena; 1 arose from the St. Peter Sandstone and 1 from the Jordan Sandstone. The nitrate concentration in the seven springs arising from the Galena Limestone ranged from 5 to 30 mg/l, the average being 16 mg/l. All seven springs were grossly contaminated with coliform bacteria. The St. Peter spring had 6 mg/l nitrate and 1 coliform/100 ml was detected. The Jordan spring contained a nitrate concentration of 7.5 mg/l. No coliform bacteria were detected.

Fluctuations in Well Water Contamination Through Time

The fluctuations in levels of contamination through time are described for a group of seven wells in Figures 2 and 3. Six of these wells were drilled through the Galena Limestone aquifer into the St. Peter Sandstone. They were constructed between 1964 and 1970. Only well number 4 was drilled prior to 1964. It was included in our study as an example of an older type well terminating in the upper limestone. Well number 4 is believed to have been drilled to its present depth of 200 feet in 1935. The two wells numbered 1 and 2 in this group are cased and well number 2 also has the annular space between the wall of the well and the casing grouted with concrete.

The striking contrast between the deeply cased wells and those not cased through limestone is again evident. It should also be noted that the two wells located near barnyards (numbers 3 and 4) have the highest levels of nitrate. Both exceeded the United States Public Health Service maximum for drinking water. The remaining three wells (numbers 5, 6, and 7) served suburban residents. The nitrate concentrations in these wells fluctuated from 8 to 50 mg/l. Figure 4 shows the distances between five of the wells and from sources of pollution. Well numbers 2 and 4 are not shown in Figure 4. Well number 2 serves suburban residents and is not near a barnyard. Well number 4 is located 75 feet from a barnyard. Coliform contamination of the seven wells is described in Figure 3. Wells 5, 6, and 7 showed silt in the water following extremely heavy rains in September of 1972. High coliform counts accompanied the silt. The residents served by well number 6 reported muddy water on several occasions following rains during the year and a half that we monitored the well. A sharp increase in coliform contamination always accompanied the muddy water. The fluctuations of up to 5 fold in nitrate levels and the extreme changes in the number of coliform bacteria observed in this group of wells point up the limitations of a single water test. A well may test safe for both nitrate and bacteria at one date and at another date test unsafe in one or both categories.

Well Water Nitrates Correlate with Proximity to Barnyard

A correlation of nitrate concentration to proximity to barnyard was found in a group of 33 wells (Fig. 5). Wells located near barnyards tend to show greater concentrations of nitrates than wells located greater distances away. The correlation was found to be significant at the 95% confidence level.

A Characterization of Enteric Bacteria in Well Water

Fecal coliform and fecal streptococci levels were determined in water samples from 15 wells which tested high in total coliform bacteria. A ratio of 4 and above fecal coliform divided by fecal streptococci is considered to indicate human rather than animal pollution. Only two wells of the 15 indicated human pollution. In both instances the wells were located within 50 feet of a septic tank drainfield. All other wells in the group were 75 feet or more from a domestic sewer system. One of the two wells showing a FC/FS ratio greater than 4 was sampled four times at week intervals. Two samples had ratios greater than 4 indicating that the pollution was predominantly of human origin and two samples had ratios between 1 and 4 indicating that the pollution was of mixed origin.

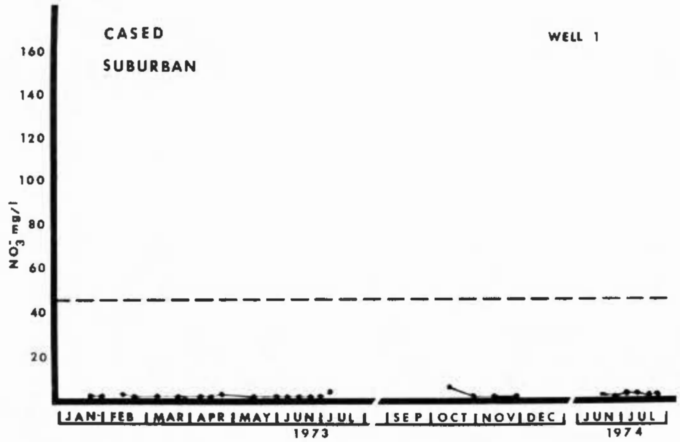
Biochemical characterizations of isolates from eight polluted wells were made. The results of these partial characterizations are shown in Table 3. The isolates were obtained from brilliant green and XLD agar plates following enrichment on tetrathionate broth. The Inolex multi-test system was employed in this characterization.

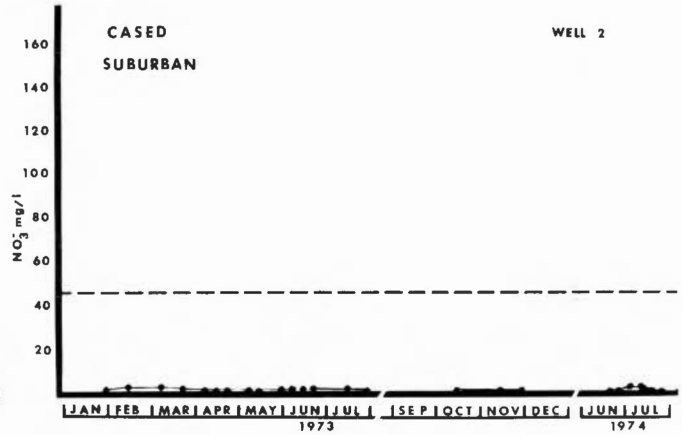
DISCUSSION

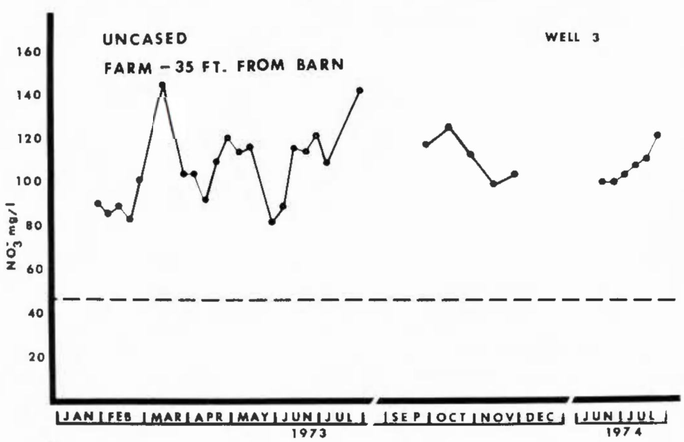
The Case for Casing Deep Wells

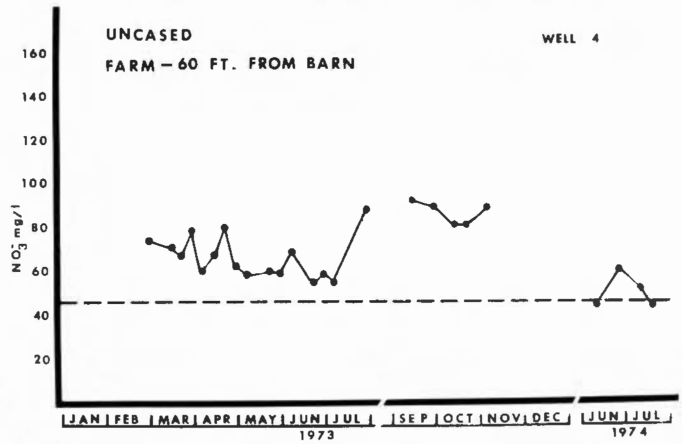
The data presented here clearly demonstrates that wells drilled into

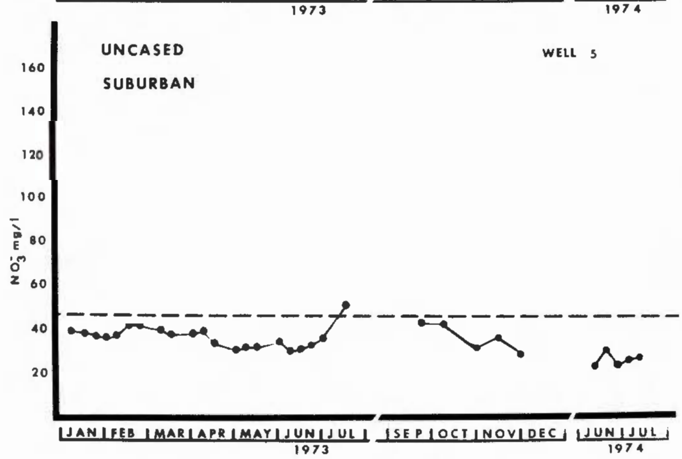
Figure 2. *Fluctuations in nitrate concentrations in 7 wells. Wells numbered 1 and 2 are located in suburban residential area and are deeply* cased. *Wells numbered 3 and 4 are located near barnyards and are* uncased *through limestone. Wells numbered 5, 6, & 7 are located in a suburban residential area and are* uncased *through limestone. All wells except number 4 terminate in St. Peter Sandstone.*

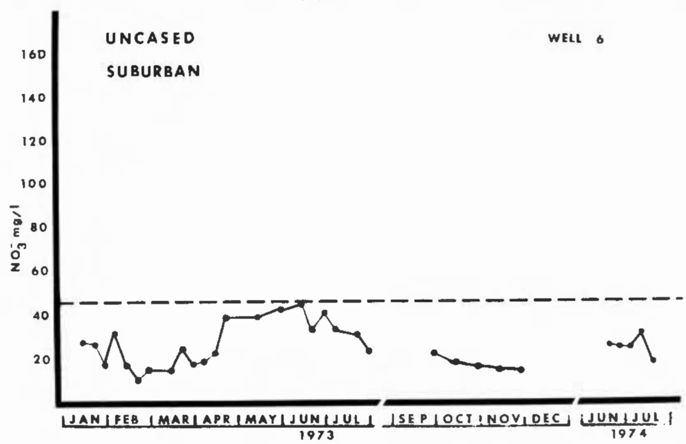

CASED
SUBURBAN
WELL 1
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974


CASED
SUBURBAN
WELL 2
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974


UNCASED
FARM – 35 FT. FROM BARN
WELL 3
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974


UNCASED
FARM – 60 FT. FROM BARN
WELL 4
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974


UNCASED
SUBURBAN
WELL 5
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974


UNCASED
SUBURBAN
WELL 6
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
SEP OCT NOV DEC
JUN JUL
1973
1974

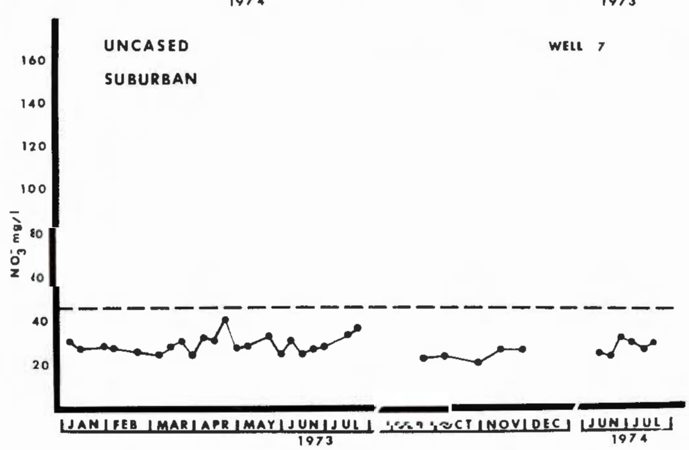

UNCASED
SUBURBAN
WELL 7
160
140
120
100
80
60
40
20
NO_3^- mg/l
JAN FEB MAR APR MAY JUN JUL
OCT NOV DEC
JUN JUL
1973
1974

Table 2. *Geologic Data on the Seven Study Wells*

Well No.	Year Drilled	Elevation at Well Head in feet	Total depth in feet	Elevation at bottom of well in feet	Total amount of casing in feet	Depth at top of St. Peters Sandstone from drilling logs (in feet)
1	1970	1165	365	800	271.5	267
1	1964	1210	375	790	247.5	275
3	1966	1148	310	838	29	268
4	1935	1210	200	1010	30	—
5	1966	1145	360	785	31	265
6	1965	1150	367	783	43	270
7	1964	1135	330	805	27	260

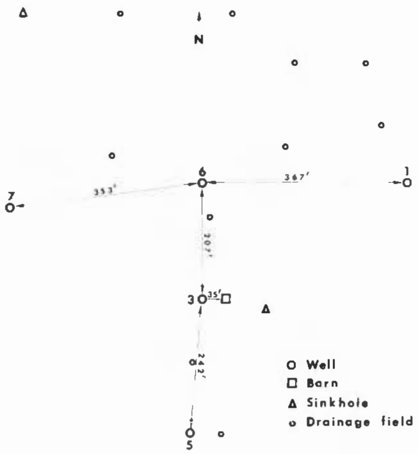


Figure 4. *Location of 5 wells tested periodically during 1973 and summer 1974 relative to probable sources of pollution. The wells shown are located in the northeast ¼ of section 9 in Decorah township, Winneshiek County. The sinkhole located 300 feet north from well number 7, which is active and growing, first appeared in 1970. Running water beneath the surface of ground can be heard at a site 200 feet south of well number 7 during and immediately following heavy rains. Not shown – well number 2 located ¾ mile north of well number 6 in the southeast ¼ of section 4, Decorah township and well number 4 located 2 miles northeast of well number 6 in the southeast ¼ of section 35 in Canoe township, Winneshiek County.*

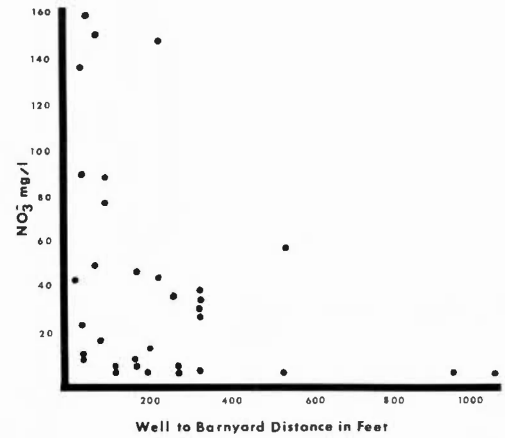


Figure 5. *Relationship of nitrate concentration in well water to distance from barnyard.*

sandstone aquifers through overlying limestone become polluted with surface runoff unless the limestone unit is cased off. However, a properly constructed well will provide an abundant supply of ground water free from coliform bacteria and low in nitrate at nearly any location in northeastern Iowa. Only during the past decade have the deep sandstone aquifers been extensively tapped as a source of water for farms and suburban homes. Many of these wells have not been cased.

Uncased wells act as shafts providing avenues for contamination to travel rapidly to the deeper water bearing formations. Frequently a shale layer as pictured in Figure 6 separates aquifers. A well which does not case out overlying aquifers destroys the natural shale barriers between near-surface aquifers and the deep aquifer. Crevices and solution channels of all sizes have been encountered by well drillers in northeastern Iowa. During our study we received numerous reports of grout from a recently drilled well appearing in an old well up to 100 feet from the new well. One report mentioned that the detergent used in well drilling appeared in a neighboring well about 1000 feet away shortly after the drilling of a new well. We also heard reports of a chlorine taste in the water of wells neighboring a well which was super chlorinated in an attempt to rid it of contaminating bacteria.

Sinkholes are direct connections to the underlying limestone aquifers. The movement of material from sinkholes through limestone was clearly demonstrated by Hoilien (1968). Malachite green dye placed in a sinkhole in Ludlow Township of Allamakee County, appeared ten days later in a spring 9 miles from the sinkhole.

Poblete (1972) reported that a group of 80 wells studied in 1960 near Rochester, Minnesota, showed significant amounts of pollution. Nearly ¼ of the samples contained more than 45 mg/l nitrate and measurable surfactants were detected in nearly one half of the wells. Non-biologically-degradeable detergents were in use at that date. In 1970, 10 years later, Poblete conducted a follow up study. It was found

Figure 3. *Coliform contamination in 7 wells. Wells numbered 1 and 2 are located in suburban residential area and are deeply* cased. *Wells numbered 3 and 4 are located near barnyards and are* uncased *through limestone. Wells numbered 5, 6, & 7 are located in a suburban residential area and are* uncased *through limestone. All wells except well number 4 terminated in the St. Peter Sandstone. Sampling events are indicated by tick marks below abscissa.*

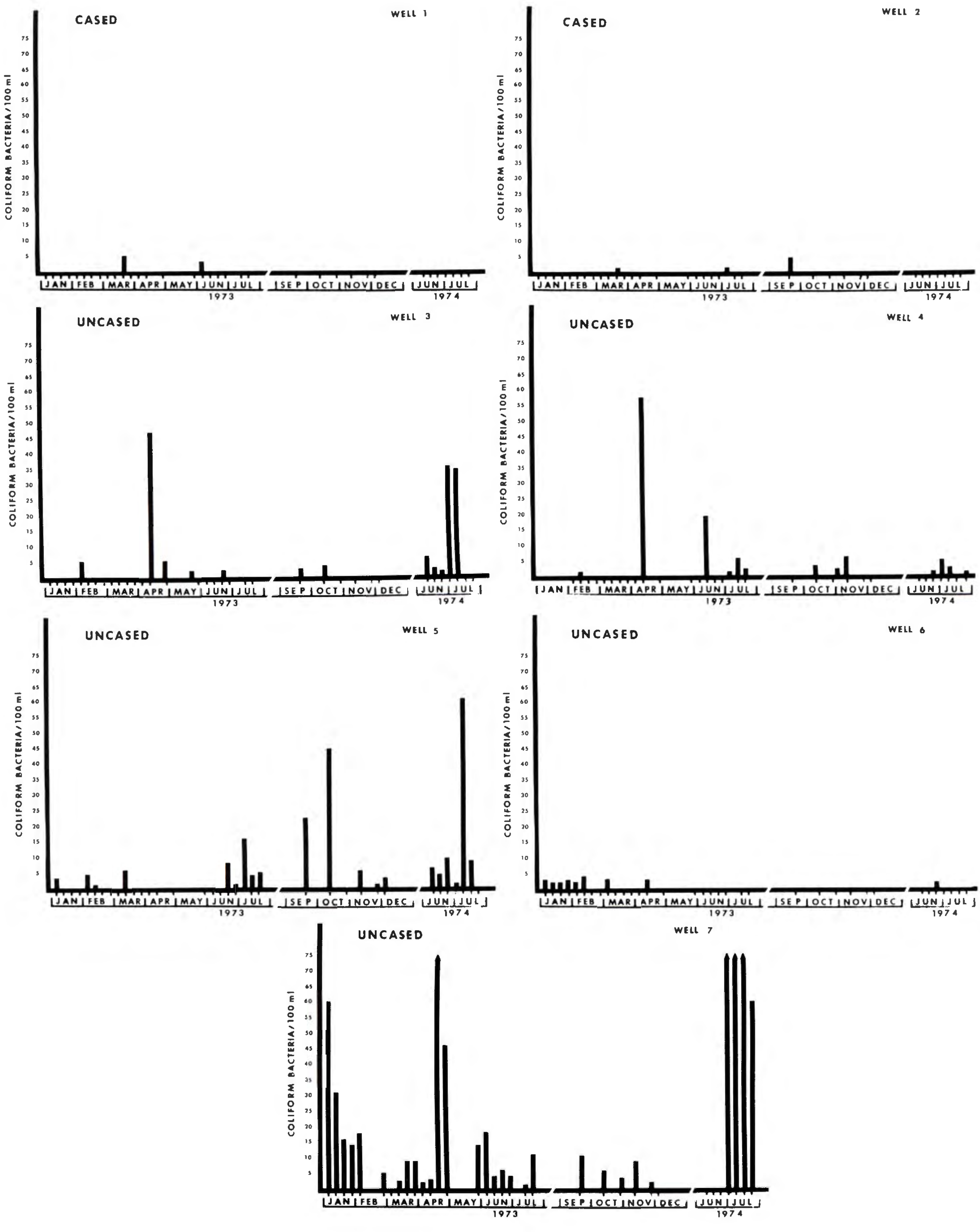

CASED
WELL 1
COLIFORM BACTERIA/100 ml
JAN FEB MAR APR MAY JUN JUL SEP OCT NOV DEC JUN JUL
1973
1974
CASED
WELL 2
UNCASED
WELL 3
UNCASED
WELL 4
UNCASED
WELL 5
UNCASED
WELL 6
UNCASED
WELL 7

Table 3. *The results of a characterization of isolates of enteric bacteria from 8 wells by the Inolex multi-test system.*

Well No.	Isolates
1	*Enterobacter agglomerans*
2	*Enterobacter agglomerans*
3	*Enterobacter agglomerans*
	Enterobacter aerogenes
	Serratia liquefaciens
	Serratia marcescens
4	*Arizonia*
5	*Enterobacter agglomerans*
6	*Enterobacter aerogenes*
	Enterobacter agglomerans
	Serratia marcescens
	Serratia liquefaciens
7	*Providencia stuartii*
	Providencia alcalifaciens
8	*Salmonella*

that the nitrate concentrations had increased by more than 10 per cent in 55 per cent of the wells and some wells showed increases of as much as 250 per cent. The St. Peter Sandstone has been lost as an acceptable water supply in several areas of Olmsted County, Minnesota. Poblete concluded that the loss of this valuable aquifer was brought about by numerous uncased or unsanitary wells which destroyed the natural filtration ability that would have otherwise protected the underlying St. Peter aquifer. Winneshiek County, Iowa, and Olmsted County, Minnesota, require permits for the drilling of a new well. Both counties employ quidelines for construction of new wells and both counties require the plugging of abandoned wells.

It is likely that a less expensive method for sealing out unwanted water than grouted-in steel casing could be developed. Since a separate inner pipe of small diameter attached to the submersed pump conducts the water to surface, the outer casing serves mainly as a seal for unwanted water. It may be possible to replace steel casing with a removable plug in situations where casing is not required for structural support. The expandable clay bentonite may show promise as one ingredient for a plug, as it is plastic and impervious to water. Also it could be slurried or drilled out easily when repairs are required on the submersed pump.

Land Usage is a Factor in Ground Water Quality

Unfortunately, proper well construction is not the complete answer to the problem of what must be done to protect our deep aquifers from contamination. When water is drawn from a deep aquifer the recharge will contain any soluble, non-degradeable pollutants contained in the overlying aquifer. The type and quantity of pollutants which gain entrance to ground water is a reflection of the overlying land usage.

We must regulate our land usage so that the levels of nitrates and other soluble non-degradeable pollutants of our ground water remain at levels compatible with our water needs. Attention should be focused on the development of more effective means for the handling of highly concentrated sources of nitrate such as domestic sewage and highly concentrated sources of manure such as feedlots.

We have noted that a correlation exists between the proximity to the barnyard and the level of nitrate in well water. We also found a concentration of nitrate of 440 mg/l in the discharge from a septic tank sewer system. McMullen (1972) analyzed runoff water quality and its relationship to the water quality of the Upper Iowa River. He found that nitrogen compounds and bacterial populations increased with rain water runoff. Klemme (1972) reported that concentrations in the Upper Iowa River during the summer averaged 2.2 mg/l of nitrate but rose to as high as 26 mg/l following a heavy rain. We checked the nitrate concentration in the out flow from the drain tiles of two corn fields during the spring melt of 1973. The nitrate concentrations ranged between 3.9 and 16.7 mg/l.

Fertilizer application to cropland apparently does not account for the excessively high concentrations of nitrate which are found in some wells in northeastern Iowa. Rather it appears that the objectionable high concentrations of nitrate result from localized highly concentrated sources such as barnyard, feedlots and domestic sewage. Proper management of these concentrated sources of waste is essential for the preservation of our ground water quality. The trend toward larger feedlots and urban development is creating localized high concentrations of nitrates and increased usage of deeper aquifers. Together, these factors dictate an urgent need for continued updating of our state waste management program.

The Effect of Contaminated Water on Human Health

The effect on human health of high nitrate concentration and enteric bacteria in drinking water is difficult to evaluate. Area physicians and veterinarians report occasional nitrate toxicities and bacterial infections in human and livestock populations which are directly attributable to the drinking water supply. There is, however, no measurement of chronic ill health due to contaminated water. Equally difficult to measure is the economic loss due to the stress incurred by livestock which drink polluted water.

We were made aware of two instances where the wells which we tested were believed to be the source of *Salmonella-Shigella* type infections severe enough to require hospitalization. We did attempt a biochemical characterization of the enteric bacteria in one of two suspected wells. An isolate from the well characterized as *Salmonella* on the Inolex system. The well was used mainly for watering livestock; however, the farmhand who was hospitalized had used the well as a source of drinking water. The attending physician reported that the causative agent of the infection characterized similar to the organisms which we isolated from the well water.

A Proposed Guideline for Well Construction and Well Abandonment

The following is a guideline for well construction that if required in northeastern Iowa and elsewhere in the state where similar geologic conditions exist would represent a major step toward the preservation of the quality of our ground-water supply. For continued development of a ground-water management policy in Iowa additional studies of well water quality should be conducted in other regions of the state. Different well construction may be required from one area to another as geologic and aquifer conditions vary.

Except where 75 feet or more of unconsolidated materials overlies limestone, the water in limestone aquifers usually shows evidence of contamination from surface water, notably elevated nitrates. Since many of Iowa's sandstone aquifers are overlain by soluble limestone, legislation is needed to protect the vast water resource of our deep aquifers.

The guideline:

A. Well construction: All new wells terminating in sandstone overlain by limestone and not covered by a minimum of 75 feet of glacial drift clay or consolidated shale rock shall be cased and pressure grouted with cement into the upper part of the sandstone. Well construction to accomplish this sealing shall be as follows:*

a. A minimum 8 inch casing shall be installed through unconsolidated materials and shall be driven to refusal into the uppermost rock formation.

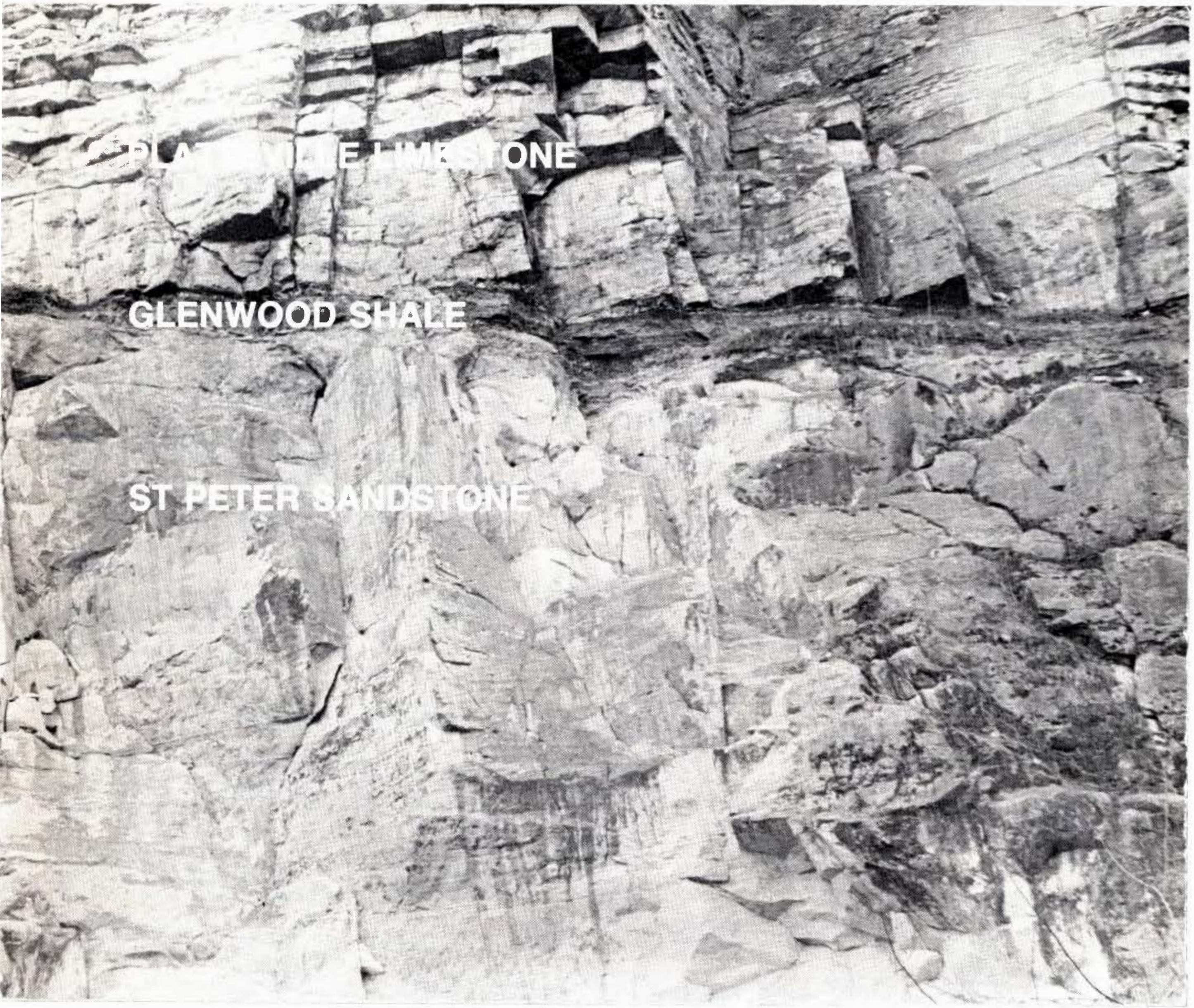


Figure 6. *Shale separating Limestone and Sandstone.*

b. An open hole of the same nominal size as the casing through the drift shall be drilled through the creviced limestone formations and at least 15 feet into a firm portion of the underlying sandstone formation.

c. A welded liner casing at least 4 inches smaller in diameter than the casing through the drift shall be installed from the surface to the upper portion of the sandstone. An uncased hole of the same diameter as the liner shall be extended deeply into the sandstone, preferably the full thickness of the sandstone.

d. The annular space between the liner and the open hole and between the liner and the outside drift casing shall be filled with cement grout. The grout shall be introduced at the bottom of the liner and forced upward.

e. Grout is a thin mortar consisting of portland cement and water or portland cement, sand and water in the following proportions:

1. One sack cement to 4½ to 5½ gallons of water.
2. One part cement, one part clean sand, and 4½ to 6 gallons water. This sand grout shall be used only where abnormal loss of grout to crevices or faults occurs. Additives to the mixture of 5% by weight of suitable materials may be used.

B. Abandoned Wells: Any well found to be contaminated beyond reclamation or any well the use of which is to be permanently discontinued, shall be filled with puddled clay or concrete throughout their entire depth, or filled with clay and tamped. It is recommended the Well Driller preform the service of closing and sealing the old well upon completion of the new well if the old well is to be abandoned.

*The proposed specifications for well construction are those employed in Olmsted County, Minnesota

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