Microbiological Activity and the Deterioration of Water Well Environments on the Canadian Prairies

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ABSTRACT Declining well yields, water quality deterioration and reduced well life have generally been attributed to the chemical and physical properties of the water well environment. New research indicates that water well deterioration can be caused by the activities of groundwater microorganisms (i.e. well bioufouling). In this study, well owners, from the M.D. of Kneehill, Alberta were surveyed to determine the extent and type of well problems in their district. Approximately 74% of the owners who replied to the survey, reported water quantity or water quality problems. Reconnaissance testing, performed on 134 wells in the study area, showed high levels of bacterial activity in 68% of the test wells. Detailed diagnostic tests clearly illustrate that this activity can significantly impact the physical integrity and sustainability of a water well. These results, underscore the importance of developing methods to diagnose and prevent well biofouling; a pervasive and yet poorly understood water well problem.

Résumé: On attribue généralement la baisse de débit de production, la détérioration de la qualité de l'eau et la réduction de la durée de vie utile des puits d'eau aux propriétés chimiques et physiques de leur environnement. Cependant, on reconnaît moins bien que l'eau souterraine contient des micro-organismes (p. ex. des bactéries) dont l'activité, en l'absence de contrôles, peut diminuer la valeur et abréger la durée de vie utile d'un puits d'eau. On a poursuivi cette étude sur l'étendue de 16 communes du district municipal de Kneehill (Alberta) avec l'objectif de cerner l'étendue et la nature des problèmes par rapport aux puits d'eau et établir le rôle éventuel de l'activité microbiologique dans leur détérioration. Environ 74% des puits d'eau de cette région éprouvent des problèmes par rapport à la qualité et au débit d'eau. L'analyse préliminaire de 134 puits a découvert des niveaux importants d'activité bactérienne dans 68% des puits. Des tests de diagnostic détaillés ont indiqué clairement que cette activité peut être très nuisible à la qualité et au débit de l'eau.

1. INTRODUCTION

Understanding the cause of groundwater supply problems and developing methods to sustain water well environments is important in maintaining and improving the quality of life in rural Canada. Many of the individuals and small communities in Canada, who rely on groundwater as a principal source of potable water, experience water quality or well yield problems. Currently, when the quality or quantity of water produced declines dramatically, wells are routinely abandoned or treatments are applied with little understanding of the cause of these problems. The cost of replacing these wells can have a significant economic impact on the owner. Correctly identifying the cause of water well deterioration offers the possibility of effective maintenance and treatment instead of well abandonment.

1.1 The Biofouling Process

Losses in water well production and water quality have traditionally been attributed to the chemical and physical properties of the water well environment. However, less recognized is that groundwater contains microorganisms (e.g. Sulfate Reducing Bacteria and Iron Related Bacteria) and the activities associated with these microorganisms can reduce the value and life of a water well. Water well deterioration caused by microbiological activity is termed biofouling. (Cullimore and Legault, 1997).

Biofouling of a water well occurs when biofilms accumulate a sufficient amount of debris to interfere with water flow and affect water quality. Installing and pumping a well increases the level of oxygen and nutrients in the well and surrounding aquifer. This encourages bacteria to colonize surfaces in and around the well intake. The bacterial colonies will form a gel-like slime or biofilm that captures chemicals, minerals and other deposits such as clays and silts, that move to the well during pumping. Some of the byproducts associated with bacterial growth, such as iron and manganese, will also become accumulated in the biofilms (Legault, 1999).

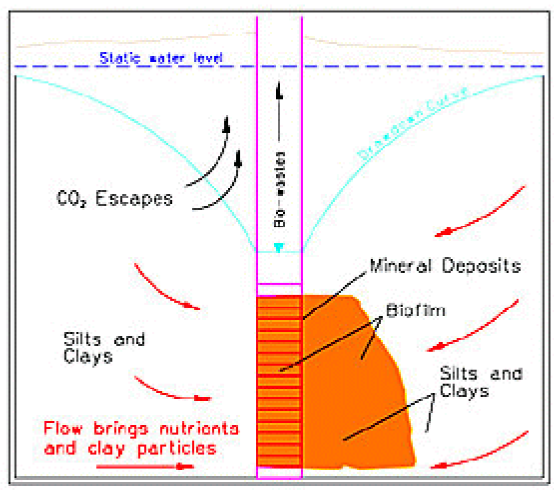


Figure 1: Water Well Biofouling

If uncontrolled, well biofouling can affect well performance in various ways. Biofilms and the debris they collect can quickly coat, harden and plug the well screen, the sand pack, the surrounding aquifer material and may even plug water lines and affect the performance of household treatment systems. In addition, the bacteria living within the biofilm can increase the rate of iron oxidation increasing iron build up, which may lead to occasional discoloration of the well water. (Legault, 1999).

1.2 Project Background

Like many regions in Canada, locating a reliable source of groundwater can be difficult in the Municipal District (M.D.) of Kneehill, Alberta and shortly after the well is installed problems such as declining well yield and water quality deterioration often develop. To address these concerns the Prairie Farm Rehabilitation Administration (PFRA) agreed to direct a series of groundwater studies in the M.D. of Kneehill. These studies led to the creation of the Sustainable Water Well Initiative (SWWI). The goal of this initiative is to work with rural communities, the water well industry, treatment specialists and researchers to investigate the causes of well deterioration and to provide improved advice on methods used to diagnose, prevent and treat well problems.

The main objectives of the studies performed in the M.D. of Kneehill were as follows:

- Review the geological and groundwater conditions in the study area to identify approaches to improve the success rate in siting water wells.
- Confirm the extent and type or water supply problems occurring within the study area.
- Determine the impacts that natural nuisance bacteria in groundwater have on water quality, well production rates, and well life within the study area and make recommendations to address these impacts

The Geological Survey of Canada and Mollard and Associates Ltd. were consulted in an attempt to improve the success rate of siting water wells. Two geological approaches were used to identify where more permeable bedrock deposits might be present: the facies approach (i.e. looking at the depositional environment of the bedrock sediments) and the lineament approach (looking at where the bedrock sediments might be more fractured). The results of these investigations are summarized in the report, "Groundwater and Water Wells in the Municipal District of Kneehill Alberta" (PFRA, 1997).

This paper summarizes the methodology and findings used to confirm the extent and type of water supply problems in the study area and to identify the potential role of groundwater microorganisms in the deterioration of water wells. This work was carried out by PFRA, Droycon Bioconcepts Inc. (DBI), the M.D. of Kneehill and, Alberta Environmental Protection (AEP).

1.3 Study Methodology

Three stages of investigation were used to meet the described objectives. First, rural homeowners were surveyed to determine the extent and type of water supply problems within the study area and an AEP database was used to collect background information on the 251 operating water wells identified in the survey. Secondly, microbiological analysis was performed on water samples gathered from 134 selected wells within the survey region. These tests were used to: establish the rate and degree of bacterial activity in wells located across the study area, identify factors that appear to enhance biofouling (e.g. geology, age of well, etc.), and select wells for more detailed investigations. The third and final stage of the investigation involved detailed diagnostic testing of seven of the wells. These tests provided evidence of the extent of biofouling and the forms of bacteria involved. In addition, the diagnostic tests were used as a well performance benchmark, permitting calculation of the relative merit of any future well rehabilitation efforts.

1.4 Site Description

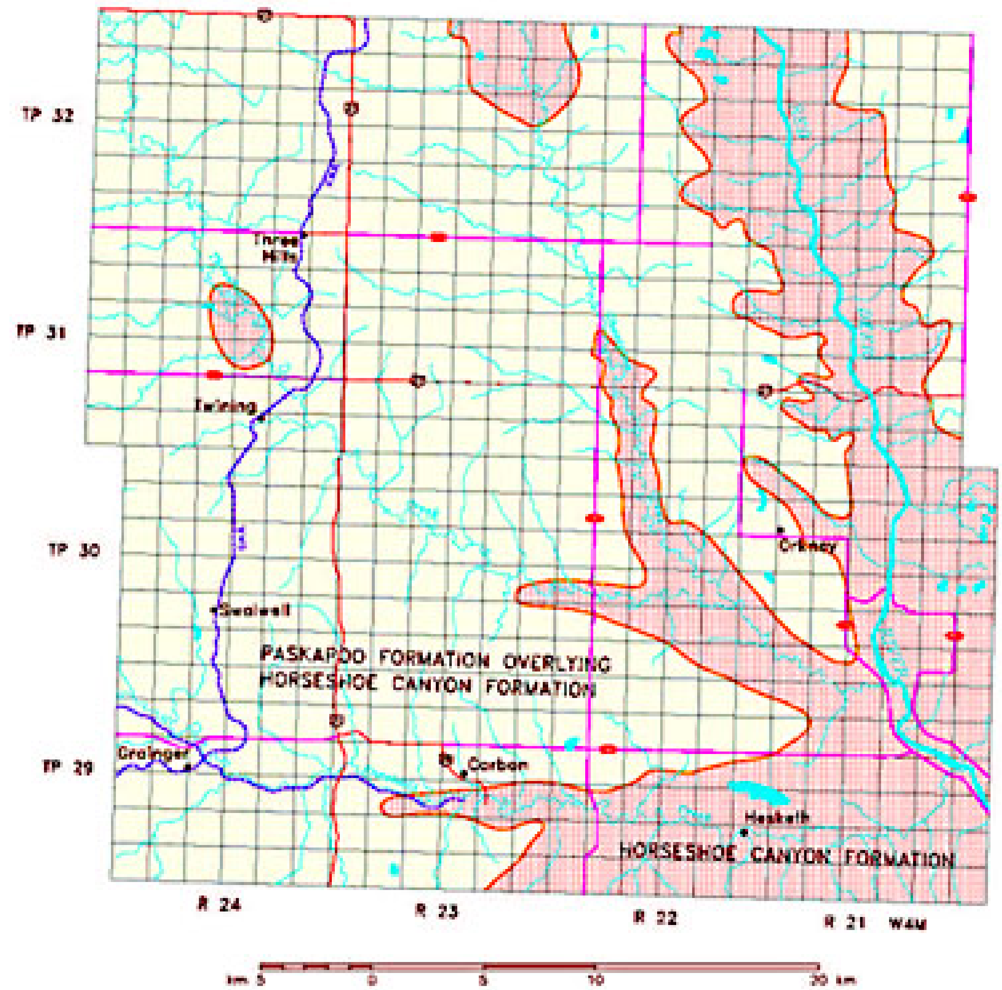
The M.D. of Kneehill is located in Alberta between Drumheller and Red Deer. The study area encompasses Townships 29-32 and Ranges 21-24, W4. This area has historically been classified as low-yielding with potential well yields between 5 to 23 L/min or 1 to 5 igpm. Virtually all of the existing wells are completed in bedrock. (Lebedin, 1995).

The uppermost bedrock formations, the Horseshoe Canyon and Paskapoo, are composed of layers of sandstone, shale and coal. Where it exists, the Paskapoo Formation overlies the Horseshoe Canyon Formation (see figure 2).

The Paskapoo formation is coarse grained with some thick sandstone lenses. In contrast the Horseshoe Canyon Formation is generally fine grained and has a high bentonite content which leads to low water supply potential. "Lineaments" are present throughout the area and are thought to represent surface expressions of fracturing in the underlying bedrock. A gas field is known to lie below the Horseshoe Canyon Formation in the south-eastern portion of the study area.

Well yields are quite variable, even between wells located relatively close together and completed in the same formation. Although many of the bedrock sediments can contain large volumes of groundwater, these sediments yield water at different rates because of the wide range in permeability. Higher yielding wells generally occur in coarser grained sandstone, coals or fractured bedrock strata (PFRA Earth Sciences Unit, 1997).

Water samples taken from wells in the project area show the water to be a sodium bicarbonate-carbonate type with Total Dissolved Solids (TDS) ranging from 1000 to 3000 mg/l. Some samples contain high concentrations of fluoride, iron, and/or sulphate (PFRA Earth Sciences Unit, 1997).



2. EXTENT AND TYPE OF WATER SUPPLY PROBLEMS

The homeowner survey was designed by PFRA and conducted by an employee of the M.D. of Kneehill. Detailed results from the survey are outlined in the report, "Groundwater and Water Wells in the Municipal District of Kneehill Alberta" (PFRA, 1997). Following is a summary of the results.

2.2 Active Wells

Of the 275 water users who responded to the survey, 220 (80%) indicated that they use wells for their main water supply. These 220 well owners reported 251 wells in use (some well owners reported using two or more wells).

The well owner survey confirmed that there is a significant water well deterioration problem from the well owners' point of view. Of the 251 wells **73.7%** (185) were reported to have water quality or water quantity problems, or both.

Reported problems were divided as follows:

- **124 wells (49.4%) had water quality problems only.** Of these 122 had ongoing concerns and 2 had seasonal concerns.
- **24 wells (9.6%) had water quantity problems only.** Of these 5 had an ongoing concern and 19 had seasonal concerns
- **37 wells (14.7%) had both water quality and quantity problems.** In these wells water quantity was general noted as a seasonal concern (35 wells) while water quality was mainly an ongoing concern (36 wells).
- **no problems were reported on 66 wells (26.3%)**

More water quality problems in the active wells were reported than water quantity problems. In total **64.1%** of the wells were reported to have water quality problems while only **24%**

were experiencing water quantity problems. This difference may due to the fact that a slight change in water quality is immediately noticeable whereas a small progressive reduction in well yield will not be realized until the supply of water no longer meets the needs of the well owner.

2.3 Abandoned and Standby Wells

The extent of the water well problem is also illustrated by 60 (**30%**) of respondents providing detailed information on 69 abandoned or standby wells. Of these 69 wells, **91.3%** (63) were reported to have water quality problems, water quantity problems or both:

- **44 wells (64.1%) had reported water quality problems an 49 wells (71%) had reported water quantity problems**
- **19 wells (27.5%) had water quantity problems only, 14 wells (20.3%) had water quality problems only, 30 wells (43.5%) had both water quality and quantity problems.**

There is a striking difference between these statistics and those for the active wells. Most of the abandoned or standby wells are not in use because of water quantity problems. A total of 71% of these wells had a reported water quantity problem whereas only 24% of the active wells have reported quantity problems. Water quality problems were similar for both active and abandoned wells: 63.8% of the abandoned or standby wells were reported to have water quality problems versus 64.1% of the active wells. It appears that well owners will continue to use their well as long as it is producing even when water quality is a concern.

Well replacement due to performance deterioration becomes increasingly likely after 15 years of well operation. Based on 153 wells with known ages only 9% less than15 years old were abandoned or put on standby. In contrast 17% of wells older than 15 years were abandoned or on standby with the median age of these wells being 20 years.

2.4 Treatment of Wells in the Study Area

Survey responses demonstrate that although well problems can be severe, corrective action is often not applied. Although about 74% of the active wells were reported to have water quality and/or quantity problems, only 31% of these wells were identified as ever having received a treatment. Shock chlorination was the only treatment method used in the study area. No data was available to determine if shock chlorination is being applied correctly or to determine its effectiveness in reducing deterioration caused by microbiological activity.

PFRA is presently performing a laboratory evaluation of well maintenance chemicals which are currently used to restore aquifer efficiencies. In addition, field projects are underway to test the effectiveness of well rehabilitation technologies. The results form these studies will be used to provide improved advice on the methods used to maintain and treat rural water wells (PFRA, 1999)

3. IMPACT OF NATURAL NUISANCE BACTERIA ON WATER WELLS

3.1 Symptoms of Biofouling

Interpretation of the well owner survey was undertaken by DBI to identify if concerns reported by well users may be related to biofouling. Taste, odour, and red and black slimes were the most common symptoms reported. Other symptoms included: mineralization, reduced well yield, and coloured water. In general, very few symptoms indicative of biofouling were reported in wells less than 5 years old.

3.2 Reconnaissance Microbiological Testing

Following the interpretation of the survey, water samples were collected, from 134 wells by PFRA staff, and tested for microbiological activity in alaboratory established by DBI in Three Hills, Alberta. Samples were generally taken from household taps after running the water for five minutes. Well owners were concerned about running out of water and would only allow the water to run for a short time.

3.2.1 Biological Activity Reaction Tests

Microbiological testing and analyses were performed by DBI using the Biological Activity Reaction Tests (BART™) system which is outlined in the BART™ Quality Control Manual (DBI, 1996). These biodetectors offer a method for detecting the presence and activity level of selected groups of potential nuisance bacteria.

Laboratory analysis consist of observing the reactions that occur in each biodetector daily for a period of 13 days. The time elapsed from the addition of water to the biodetector until an initial reaction occurs is recorded. This indicates the activity level of a bacteria group, i.e. the shorter the days to the first reaction, the more active the bacteria. When a water sample contains high levels of bacterial activity it is an indication that biofouling is occurring in the distribution system, water well or in the aquifer which supplies water to the well. Water samples were analyzed for Iron Related Bacteria (IRB) Sulphate Reducing Bacteria (SRB) and Heterotrophic Aerobic Bacteria (HAB). IRB reactions within 3 days, SRB reactions within 4 days or HAB reactions with in 1 day were considered to be indicative of high levels of bacterial activity.

3.2.2 Results of the reconnaissance testing

Of the 134 water samples collected, 68% contained at least one type of highly active bacteria:

- **67% contained highly active populations of SRB**
- **17% contained highly active populations of HAB**
- **9% contained highly active populations of IRB**

These tests indicate that 68% of the wells sampled are likely biofouled. The tests also show that wells in this area are particularly prone to SRB infestation.

3.3 Factors that May Enhance Well Biofouling

An attempt was made to correlate biofouling of wells with the geology of the study area. A review of completion data on 43 wells was carried out to identify sampled wells which drew water solely from either the Horseshoe Canyon or Paskapoo Formations. From the 43 wells examined 13 draw water from the Horseshoe Canyon Formation and 30 draw water from the Paskapoo.

The Horseshoe Canyon Formation appears to provide a more inviting environment for the growth of Sulfate Reducing Bacteria than the Paskapoo Formation. SRB were found to be the dominant bacteria in water samples taken from wells in each formation; however, only 60% of the wells in the Paskapoo formation provided water samples which contained Highly active SRB while 100% of the water samples taken from the Horseshoe Canyon contained very active SRB.

Lineament and gas field maps were also examined to identify any factors that appear to enhance biofouling. A large gas field lies below the southern end of the study area in Townships 29 and 30 of Range 22. The dominance of SRB in the study region was somewhat of a surprise to DBI as their experience in other areas has been that IRB and HAB normally tend to be more dominant in water wells. They suggest that the high levels of SRB may be due in part to the underlying gas bearing formations; the SRB could be using the permeating methane as a food source. The lineaments may provide pathways for this gas to reach the near surface.

In general, wells may contain high levels of bacterial activity soon after the well is installed. Nine of the wells included in the reconnaissance testing were under 5 years of age. Of these, 3 contained high levels of bacterial activity.

Laboratory research, performed by PFRA following the M.D. of Kneehill study, shows that although high levels of bacterial activity can quickly develop in a well, it may take a number of years for this activity to affect well yield. Owners whose usage is much less than the well's capacity would likely not notice a progressive reduction in yield due to biofouling unless they were carefully monitoring their well. In addition, well owners with water treatment equipment may not immediately notice a change in water quality until the treatment applied is no longer sufficient to remove the problem. This underscores the importance of monitoring well performance and testing water quality on a regular basis..

3.4 Intensive diagnostic Testing

During the summer of 1996, diagnostic tests were performed on seven wells within the study area. Wells chosen for this stage of the study were located throughout the study area. Diagnostic procedures included an analysis of water chemistry, gamma logging, visual inspection of pumps and discharge lines, down hole camera inspections, 2-hour pump tests and detailed microbiological testing. Pump tests were repeated in six of the seven study wells one year following the initial diagnostic work to benchmark the change in well production with respect to time.

3.4.1 Well Data

The study wells ranged in age from 1 to 20 years and well depths were between 42 and 92 meters. Four of the seven wells were constructed with PVC well casings and liners and three were constructed with steel well casings and liners. Four of the wells were active and the remaining two wells were new wells which were not in use at the time of the study.

3.4.2 Water Chemistry Analysis

Water samples were collected from the seven study wells and sent to a laboratory for major ion analysis. Results were examined to establish if there had been any change in water chemistry since the wells were last tested. Only four of the wells had been previously tested by the well owners. Iron and/or sulphate levels had increased in each of these four wells. There were no previous records on manganese levels.

There are a number of factors that can change the chemistry of water from a well. Water chemistry can be affected by changes in the flow path of water to a well or other hydrogeologic events. The oxidation of iron, manganese and sulphate compounds by bacteria can also affect the chemistry of water entering a well. Once oxidized, these compounds become part of a biofilm complex. When biofilms break up or slough off the chemistry and quality of water entering the well may change. This may account for some of the water quality changes experienced in the study wells.

3.4.3 Well Logging

To establish formation characteristics, cased and screened intervals of each of the seven study wells were gamma logged by AEP. This information was also used to determine the depth to water-bearing zones where well treatment would be most effectively applied and used to identify problems in well construction, such as improper placement of the well intake area. Data from these logs, along with well drillers descriptive logs, revealed that the water bearing layers of the study wells were generally a grey sandstone or sandy shale. Layers ranged in thickness from 1 to 9 metres (5 to 30 ft) and well intakes were often installed across a number of layers.

3.4.4 Down Hole Video Inspections

One of the most revealing diagnostic procedures involved removing the pump and running a video camera down the entire length of each well. The video logs provided a permanent visual record of the physical condition of the interior of the well casing and intake area and the degree of bacterial growth in the well. Initial down hole camera inspections were completed by the AEP.

Pumps and discharge lines from each well had black or red slime deposits on the portion of the line that was submerged. In most cases, red or black slime deposits also covered the pump and pump intake. Black slimes are generally associated with sulfate reducing bacteria, while the red slimes are associated with iron related bacteria.

Down hole camera inspections revealed heavy incrustations on the casing walls and intake areas of each of steel wells. This made viewing the intake slots very difficult. These incrustations often result from biochemical accumulation of iron, manganese and sulphate salts. Biofilms and bioaccumulates were also observed in each of the steel wells.

All of the PVC wells exhibited evidence of biofouling in the form of black growths on casing walls and at casing joints, black slime rings, black biofilms, and black strands in the slots of the liner. In most cases, the presence of bacterial growth increased with depth.

3.4.5 Pumping Tests

Pump tests were conducted, in 1996 and again in 1997, on six of the seven study wells. Specific capacity results from the tests were compared to provide some quantitative measure of the effects of biofouling on well production over time. During each pump test, water was pumped from the well for two hours at a constant rate and the water level was recorded at regular time intervals. The 2-hour specific capacity of each well was then calculated by dividing the pumping rate, which is recorded in imperial gallons per minute (igpm), by the total drawdown in feet (ft). Specific capacities are reported in Table 1 as the rate of discharge per foot of drawdown (i.e. igpm/ft).

Table 1: Pump Test Results: 1996 -1997 Specific Capacities

Well	1996 Specific Capacity (Igpm/ft)	1997 Specific Capacity (Igpm/ft)	Change in Specific Capacity (Ipgm/ft)
1	0.798	0.774	-0.024 (3.0%)
2	0.157	0.156	-0.001(0.6%)
4	0.065	0.069	+0.004 (6.1%)
5	N/A	0.023	N/A
6	0.295	0.250	-0.045 (15.2%)
7	0.119	0.100	-0.019 (16.0%)

In 1996, pump tests were performed on only 5 of the 6 wells. Well # 5 was unable to maintain a constant discharge rate, so the pump test was aborted. Specific capacities in the remaining five wells ranged from 0.065 to 0.842 igpm/ft.

A comparison of 1996 and 1997 pump test results indicate that the specific capacity had decreased in four of the study wells and increased slightly in one of the study wells. Losses ranged from 0.6% to 16.0% compared to 1996 specific capacities. Although there are many factors that can lead to reduced production in a well, these losses likely resulted from the bacterial activity observed in each well.

3.4.6 Detailed Microbiological Testing

During the initial pump tests water samples were collected from each well and analyzed for microbiological activity. Water samples were collected at set time intervals during the pump tests (i.e. 5, 10, 30, 60 and 120 minutes) and were analyzed for the possible presence and activity levels of IRB, SRB and HAB.

Test results confirmed that each of the study wells were heavily biofouled. Each well contained high levels of SRB and IRB activity and four wells contained high levels of HAB activity. SRB and IRB were likely responsible for the black biofilms and red slimes observed in the camera inspections.

4. CONCLUSIONS

A significant number of wells in the M.D. of Kneehill, Alberta are experiencing well deterioration. From the 251 active wells included in the survey, 74% were experiencing water quality, water quantity problems or both. In addition, 220 well owners identified 63 wells that were abandoned or placed on standby due to water quality or quantity problems.

Despite concerns of water quality, well owners will often continue to use their wells as long as they are producing. Of the abandoned or standby wells, about 71% had reported water quantity problems whereas only 25% of the active wells were reported to have water quantity problems. Water quality problems were consistent for both active and abandoned wells: 63.8% and 64.1%.

Most of the problems in the M.D. of Kneehill appear to stem from the effects of biofouling. Many of the reported symptoms of water well degeneration could be explained as biofouling events. Reconnaissance BART^{TM} tests indicated that 68% of the wells sampled were likely biofouled. Camera inspections clearly showed microbiological growth in each of the seven wells. Detailed microbiological testing confirmed that all seven wells were biofouled. In addition, pump tests conducted in 1996 and 1997 on six of the seven study wells indicated that the specific capacity had decreased over the year in four of the wells.

The wells in this area are particularly prone to infestation with Sulfate Reducing Bacteria (SRB). SRB was the dominant bacteria found in the 134 wells sampled during the reconnaissance testing, as well as in the seven wells for which detailed diagnostic testing was carried out.

Biofouling was more prevalent for wells in the Horseshoe Canyon Formation than in the Paskapoo Formation. All wells tested in the Horseshoe Canyon Formation were identified by DBI as containing high levels of SRB bacterial activity. For Paskapoo Formation wells, the percentage of wells containing high levels of SRB activity was only 66%.

The relatively low percentage of treated wells clearly indicates that well owners do not recognize the role that preventative maintenance and treatment can play in improving or maintaining their water supply.

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