SUSTAINING WATER WELL INFRASTRUCTURE IN AN AGRICULTURAL SETTING – RURAL MUNICIPALITY OF MOUNT HOPE SASKATCHEWAN

Harry Rohde, B.Sc., P.Eng., Prairie Farm Rehabilitation Administration (PFRA) – Agriculture and Agri-Food Canada (AAFC) Regina, Saskatchewan
Twyla Legault, B.A.Sc, Prairie Farm Rehabilitation Administration (PFRA) – Agriculture and Agri-Food Canada (AAFC) Regina, Saskatchewan

ABSTRACT
As part of the Sustainable Water Well Initiative (SWWI), a study was conducted in the Rural Municipality of Mount Hope, Saskatchewan, to identify factors that may cause or accelerate biological plugging of water wells. Information was collected on 183 water wells using a well owner survey and microbiological testing was conducted on 55 randomly-selected wells. Results from the biological testing indicate that many of the sampled wells are at risk of biofouling. The results of this study also suggest that the availability of nutrients may enhance biofilm development and increase the risk of biofouling. Further studies are still required to better understand the factors that cause biofouling in the water well environment.

RÉSUMÉ
Dans le cadre de l'Initiative de puits d'eau durables (IPED), une étude a été menée dans la municipalité rurale de Mount Hope, Saskatchewan, pour déterminer les facteurs qui peuvent causer ou accélérer l'obturation biologique des puits d'eau. L'information a été recueillie sur 183 puits d'eau à l'aide d'une enquête auprès de propriétaires de puits, et des tests microbiologiques ont été effectués sur 55 puits choisis au hasard. Les résultats des tests microbiologiques indiquent que de nombreux puits sélectionnés comportent des risques d'encrassement biologique. Les résultats de cette étude indiquent aussi qu'une disponibilité accrue de nutriants peut favoriser le développement de film biologique et accroître les risques d'encrassement biologique. D'autres études sont requises pour mieux comprendre les facteurs qui causent l'encrassement biologique dans les puits d'eau.

1. BACKGROUND

Water wells are the primary source of water for most rural residents on the Canadian Prairies, with about 400,000 wells installed across the Prairies since 1960 (Lebedin et al, 2000). In Saskatchewan, about 45% of the population currently uses groundwater for drinking purposes. Of this total, around 23% are rural residents (Vogelsang, 1997). Therefore, understanding the cause of groundwater supply problems and developing methods to maintain the reliability of water well environments is fundamental in sustaining and improving the quality of life for the rural sector. Also, correctly identifying the reasons of water well deterioration allows for effective maintenance and treatment, rather than well abandonment.

The Prairie Farm Rehabilitation Administration (PFRA), an agency of Agriculture and Agri-Food Canada, established the Sustainable Water Well Initiative (SWWI) to deal with issues associated with declining well yield and water quality in rural water wells. The goal of this initiative is to work with rural communities, the water well industry, treatment specialists and researchers to investigate the various causes of water well deterioration and to provide improved advice on methods used to diagnose, prevent and treat well problems.

One of the least understood phenomena is the effect that microbiological activity has on the water well environment, and therefore, the SWWI has attempted to address this issue. Groundwater microorganisms and their associated activities can reduce the value and life of a well. Water well deterioration caused by microbiological activity is termed biofouling. Biofouling begins when bacterial colonies form a gel-like slime or biofilm. This biofilm captures minerals, nutrients, organics and other deposits such as clays and silts that move to the well during pumping. Biofilms and the debris they collect can quickly coat, harden and plug well screens, the sand pack and the surrounding aquifer material, and may even plug water lines and affect household treatment systems. Biofouling generally becomes evident when biofilms accumulate a sufficient amount of debris to interfere with water flow and affect water quality.

This paper describes a case study undertaken to identify the extent and type of water well problems encountered in an agricultural setting in rural Saskatchewan, and also attempts to determine the role that microbiological activity plays in the overall deterioration of a groundwater supply.

2. INTRODUCTION

The Rural Municipality (R.M.) of Mount Hope #279 is located approximately 80 kilometers north of Regina, Saskatchewan, as shown in Figure 1. Like many regions in Canada, locating a reliable source of groundwater can be difficult, and once a well is installed, problems such as declining well yield and water quality deterioration often develop. To better understand the factors that lead to water well deterioration a study was undertaken by the PFRA, in cooperation with the R.M. of Mount Hope.

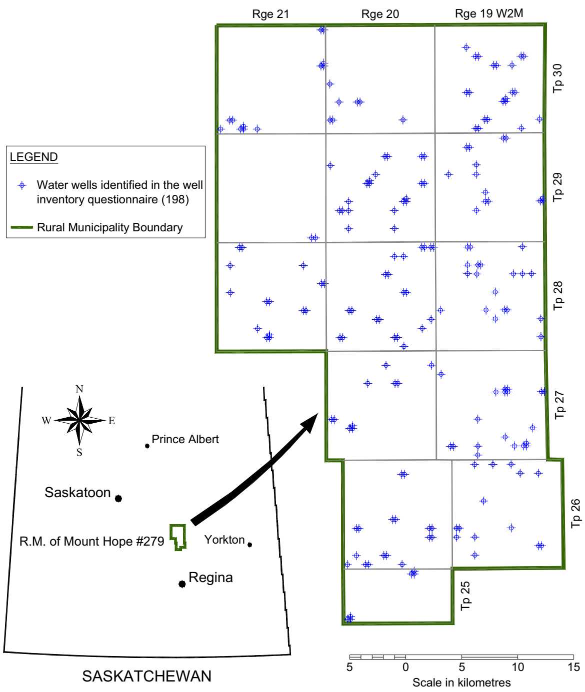

Figure 1: Location Plan

The main objective of this study was to assess the state of wells within the study area and to identify the type, extent and possible causes of water well problems.

The field study was conducted from August to October, 2000, and consisted of two data collection components. First, rural homeowners were contacted by telephone to gather basic water well data. Secondly, microbiological testing and water chemistry testing was performed on water samples collected from randomly-selected wells.

In October 2003, a further analysis of the data was conducted to determine if the water chemistry data could be used to identify wells that are at risk of biofouling.

3. WATER WELL INVENTORY

The purpose of the water well inventory was to determine the state of water wells within the R.M. of Mount Hope. A comprehensive questionnaire was developed to collect pertinent data from well owners, which was then entered into a database. The provincial water well database was also used to provide background information on the wells identified by the well owners. A total of 193 wells were identified in this inventory and data was collected on 183 of these wells. A summary of the basic information provided by the well owners is shown in Table 1.

Table 1. Water Well Questionnaire Results

Water Well Inventory: Questionnaire Data	Statistical Data	
	Number	Per Cent
Wells with information	183	95%
Active Wells	131	72%
Abandoned/Inactive Wells	52	28%
Water Supply Information (for the 131 active wells)		
Wells with adequate yield	118	90%
Wells used for drinking water	60	46%
Noticeable reduction in yield	12	9%
Water Quality Information (129 of 131 active wells)		
Excellent or good water quality	62	48%
Fair or poor water quality	67	52%
Noticeable decline in quality	16	12%
Water Treatment Information (for the 131 active wells)		
Wells that have been treated	50	38%
Wells with treatment units	31	24%

3.1 Water Quality Concerns

A review of the questionnaire data showed that water quality appears to be the main problem for many of the 131 active wells reported in the R.M. of Mount Hope. Over 50 per cent of the wells are reported to have fair to poor water quality (see Table 1). Although only 12 per cent of the wells have reported a noticeable deterioration in water quality, there appears to be various ongoing water quality concerns. Some of the general concerns expressed by well owners are illustrated in Figure 2.

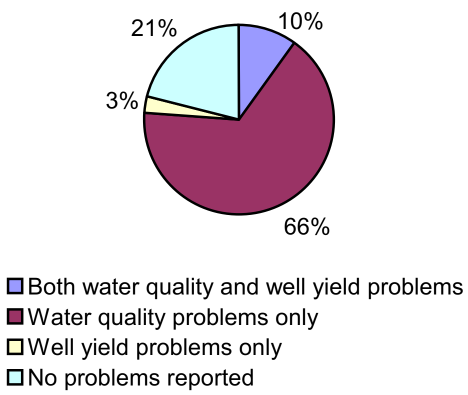

Figure 2. Water Well Owners Concerns

A more detailed review of the questionnaire responses for the 131 active wells, in regards to the water quality information, shows that:

- 76% reported at least one water quality problem
- 54% reported high iron concentrations
- 42% reported staining of plumbing fixtures

The main water quality problem identified was the presence of iron, with over half of the wells reporting high iron levels.

Although 50 per cent of well owners reported fair or poor water quality and about 76 per cent reported at least one water quality problem, only 38 per cent of the wells had been treated at least once in their lifetime (see Table 1).

3.2 Potential Biofouling Symptoms

In the well inventory questionnaire, well owners were also asked questions that may be indicative of biofouling. Symptoms such as a reduction in well yield, a decline in water quality due to taste, odour, colour, presence of gas in the water, mineralization and slime on pumps were felt to be indicative of biofouling. For the 131 active wells, 62 per cent, for a total of 81, reported at least one of these symptoms. The questionnaire results for the symptoms that may be related to biofouling are provided in Table 2.

Table 2. Potential Biofouling Symptoms

Potential Biofouling Symptoms	Statistical Data	
	Number	Per Cent
Well yield decline	12	9%
Water quality deterioration	16	12%
Taste	31	24%
Odour	30	23%
Colour	23	18%
Natural Gas in water	7	5%
Mineralization	26	20%
Slime on pumps	9	7%

4. MICROBIOLOGICAL AND WATER CHEMISTRY TESTING

The purpose of the microbiological testing was to determine the extent and degree of biological activity in the water wells. The most common bacteria involved in the biofouling of water wells are iron related bacteria (IRB), sulfate reducing bacteria (SRB) and heterotrophic aerobic bacteria (HAB). These three types of bacteria are often manifested in the following manner (DBI, 1999):

- IRB: aerobic bacteria that grow in the presence of oxygen, causing the formation of slimes, clogging, encrustations, water discolouration or corrosion.

- SRB: anaerobic bacteria that generate hydrogen sulfide (H_2S), which results in Arotten egg@ odours, blackening of equipment and water, black slime formation and the initiation of corrosive processes.

- HAB: aerobic bacteria that degrade organics as their source of energy and carbon. These bacteria cause much of the biodegradation that occurs under aerobic conditions, resulting in the formation of slimes, taste and odour problems, and cloudiness in the water.

Microbiological testing commenced in September 2001, after the completion of the water well inventory. Water samples were collected from 50 randomly-selected wells identified in the water well inventory. Five additional wells were also sampled, since they were tank-loading wells operated by the R.M. of Mount Hope.

Water chemistry tests were also conducted on 30 of the randomly-selected wells. Results from these analyses were compared to determine if a correlation exists between potential nutrients such as nitrate and dissolved organic carbon, and the observed microbiological activity.

4.1 Testing Methodology

Microbiological testing of the water samples was performed by the PFRA using the Biological Activity Reaction Tests (BARTJ), which were developed by Droycon Bioconcepts Incorporated (DBI) of Regina, Saskatchewan. A detailed description of this testing method is provided in the BARTJ User Manual (DBI, 1999). The biodetectors offer a simple method for detecting the presence and activity level of selected groups of potential nuisance bacteria that cause biofouling problems. In this study, the HAB-BARTJ (heterotrophic aerobic bacteria), the IRB-BARTJ (iron related bacteria) and the SRB-BARTJ (sulfate reducing bacteria) were used for microbiological testing.

Water samples were collected in sterile containers, placed in a cooler and sent for analysis, the same day, to the PFRA Technology Adaptation Facility in Regina. These samples were generally taken from the port (tap) closest to the well, usually at a hydrant or outside house tap. Before taking the sample the port was fully opened and allowed to run for five minutes.

In Regina, the water samples were placed in the BARTJ biodetectors and observed for a period of 10 days. The time elapse from the addition of water to the biodetector until an initial reaction occurs is then 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 microbiological activity, biofouling is potentially occurring in the well, the surrounding aquifer or within the distribution system.

The 55 water samples were also tested for nitrate at the PFRA Technology Adaptation Facility, using ion-selective electrodes (i.e. nitrate probes). These probes were used to identify water samples containing nitrate levels above 10 mg/L (as NO_3^-).

Thirty of the 55 wells, which were tested for microbiological activity, were also tested for water chemistry and total coliforms at the Saskatchewan Research Council (SRC) Analytical Laboratory, in Saskatoon, Saskatchewan. The samples for water chemistry analysis and coliform testing were collected in sterile containers supplied by the SRC, using the same sampling procedures previously described. A general water chemistry analysis was performed, which included tests for nitrate, iron and dissolved organic carbon.

5. MICROBIOLOGICAL TEST RESULTS

The BARTJ analysis showed that 43 (78%) of the 55 sampled wells contain at least one type of highly active bacteria, which is generally indicative of biofouling. Also, almost all of the remaining wells have medium levels of either IRB, SRB or HAB activity. This is consistent with results from other studies, such as the M.D. of Kneehill study in Alberta, which indicate that biofouling is a progressive process (PFRA, 1997).

When the BARTJ results are compared to the symptoms reported by well owners in the well inventory questionnaire, such as Arotten egg@ odour, unpleasant taste, corrosion and the formation of black slimes, there is very poor correlation. This may be due to the fact that the sampled wells were randomly-selected, and therefore, the wells with biofouling symptoms were not always sampled.

5.1 Iron Related Bacteria (IRB)

As shown in Figure 3, IRB appears to be the dominant bacteria, with 40 (73%) of the sampled wells containing high levels of IRB activity. Medium levels of activity were observed in 8 (15%) of the wells and low levels were observed in 4 (7%) of the wells. Three wells recorded no reaction within the 10 day test period.

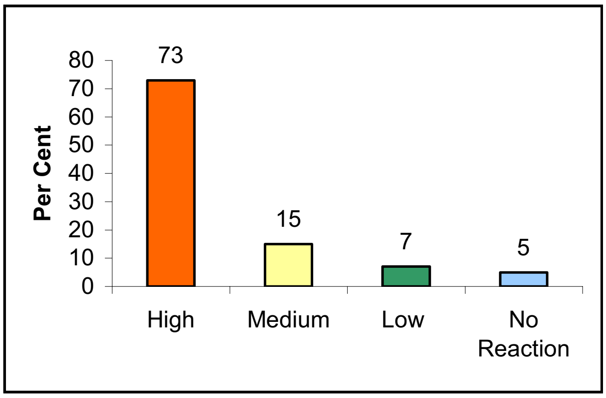

Figure 3. Iron Related Bacteria Activity Levels

5.2 Sulfate Reducing Bacteria (SRB)

Sulfate reducing bacteria are also present in many of the sampled wells, with 23 (42%) wells containing high levels of SRB, as shown in Figure 4. However, SRB are less dominant than IRB, with 23 (42%) of the sampled wells containing low levels of SRB activity or recording no reaction at all.

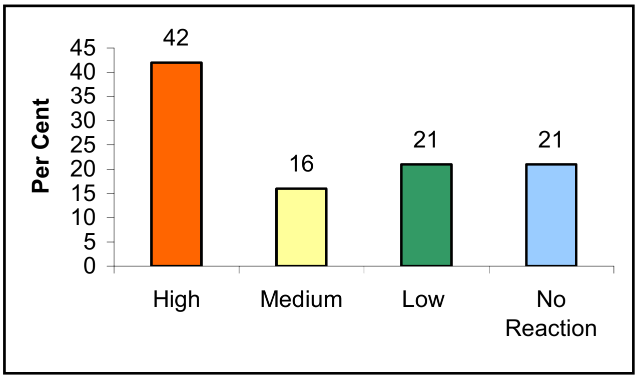

Figure 4. Sulfate Reducing Bacteria Activity Levels

5.3 Heterotrophic Aerobic Bacteria (HAB)

The HAB activity levels in the sampled wells are shown in Figure 5. As shown in Figure 5, 69% (38) of the sampled wells have high or medium levels of HAB, and about 56% of these wells were also reported by the well owner to have at least one biofouling symptom.

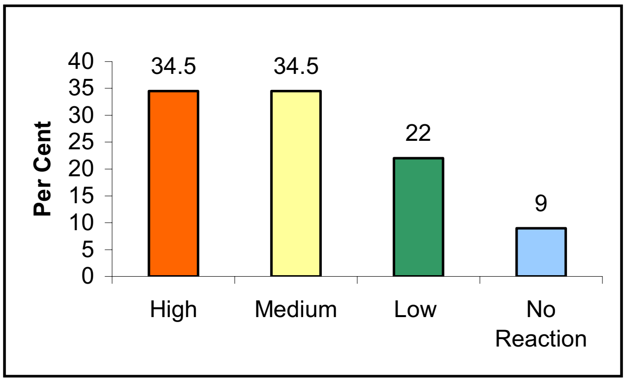

Figure 5. Heterotrophic Aerobic Bacteria Activity Levels

6. NITRATE TEST RESULTS

In this study, of the 55 water samples collected, nitrate analyses (as NO_3^-) indicated that 22 (40%) of the wells had nitrate levels of 10 mg/L or greater, and 10 (18%) of the wells had nitrates levels of 45 mg/L or greater. The study also revealed that elevated nitrate levels were often found in wells where the well owner reported no water quality problem. Therefore, the perception of the well owner is not always indicative of the actual water quality. The nitrate analysis results are shown in Figure 6.

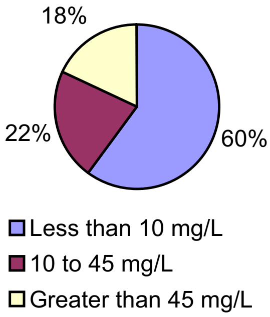

Figure 6. Results of Nitrate Analysis (as NO_3^-)

Wells in the study area with nitrate levels in excess of 45 mg/L were usually situated within natural drainage courses and at sites where the surface materials consists of silty fine sand or sandy clay. Elevated nitrate levels also signal that other contaminants could easily migrate into the surrounding aquifer.

7. FACTORS THAT CONTRIBUTE TO BIOFOULING

Understanding the factors that contribute to elevated levels of microbiological activity in water wells may assist in identifying wells at risk of biofouling. Therefore, an attempt was made to identify water quality parameters that may encourage elevated levels of microbiological activity.

Thirty of the water samples tested for microbiological activity were also tested for dissolved organic carbon (DOC), iron and nitrate at the SRC laboratory. The test results show that DOC levels range from 2.9 mg/L to 20 mg/L, with a median level of 5.3 mg/L, iron levels range from 0.002 mg/L to 15 mg/L, with a median level of 1.63 mg/L and nitrate levels range from non detectable to 440 mg/L, with a median level of 6.75 mg/L.

Nine of the 30 samples, which were tested for water chemistry, contained high levels of IRB, SRB and HAB activity. Table 3 shows the water chemistry of these samples. Seven of the 30 samples contained low or medium IRB, SRB and HAB activity. Table 4 shows the water chemistry of the samples with low or medium levels of microbiological activity.

A comparison of the water chemistry data to the microbiological data shows that microbial activity is generally higher in samples with high levels of nitrate and DOC. The water samples with high levels of IRB, SRB and HAB activity have a median DOC level of 8.4 mg/L, which is 3.1 mg/L higher than the median DOC level of all samples tested. In addition, the samples with high IRB, SRB and HAB activity have a median nitrate level of 71 mg/L, which is much higher than the overall median nitrate level of 6.75 mg/L. In comparison, water samples with only low to medium levels of microbiological activity generally have DOC and nitrate levels which are lower or equal to the median DOC and nitrate levels of all samples. This suggests that wells with high levels of nutrients in the source water may be at a greater risk of biofouling than wells with low levels of nutrients. However, further research is still necessary to determine which of these parameters has the greatest impact on microbiological activity.

Table 3. Water Chemistry of Samples Containing High Levels of Microbiological Activity

Sample Number	DOC (mg/L)	Iron (mg/L)	Nitrate (as NO_3^-) (mg/L)
10	16	0.018	440
11	8.4	15.000	105
12	18	0.069	48
13	16	0.004	299
17	2.9	0.002	71
18	20	0.760	217
20	5.5	0.011	42
30	5.2	7.500	0
39	3.1	4.000	0.22
Median	**8.4**	**0.069**	**71**

Table 4. Water Chemistry of Water Samples Containing Low or Medium Levels of Microbiological Activity

Sample Number	DOC (mg/L)	Iron (mg/L)	Nitrate (as NO_3^-) (mg/L)
21	4.5	5.7	2.2
22	5.3	5.7	0.54
24	5	0.062	4.2
31	5.3	4.4	0
35	4.2	0.4	0
38	5.3	5.0	2.3
40	4.6	5.2	0.7
Median	**5.0**	**5.0**	**6.0**

Iron levels were generally lower in the water samples with high levels of microbiological activity. The water samples with high levels of IRB, SRB and HAB activity have a median iron level of 0.069 mg/L, which is 1.56 mg/L lower than the median iron level of all samples tested. However, water samples with low to medium levels of microbiological activity show a median iron level of 5.0 mg/L, which is 3.37 mg/L higher than the median of all the samples tested.

It is suspected that iron precipitates before it reaches the water sampling port due to the activities of iron bacteria in the well. Some types of iron bacteria are known to accelerate the oxidation of ferrous iron which leads to the formation of ferric iron. Ferric iron is less soluble and will therefore tend to settle out in the well and become part of the biofilm on well screens, pumps and in pipelines. This may explain the low levels of iron in the water samples that contain high levels of microbiological activity.

8. CONCLUSIONS

Water quality appears to be the main concern of water well owners in the R.M. of Mount Hope. In the water well questionnaire, 76 per cent of the wells were reported to have at least one water quality problem and only 46 per cent of the wells were being used for drinking water. Also, the main water quality problems reported by well owners were related to high iron concentrations.

Microbiological testing revealed that 76 per cent of the sampled wells contain at least one type of highly active nuisance bacteria. Biofouling is likely occurring to some degree in each of these wells. However, the study results show that high levels of bacterial activity may not immediately result in noticeable reductions in yield or observable changes in water quality. For this reason, it is essential that wells be regularly monitored using microbiological testing, chemical analysis and pump tests for early detection of well biofouling and other well problems.

In the study area, iron related bacteria (IRB) are the most prominent nuisance bacteria in the wells, with 73 per cent of the sampled wells containing high levels of IRB activity. However, biofouling does not appear to contribute to the elevated levels of iron in the groundwater as water samples with high levels of iron tended to have low to medium levels of IRB, SRB and HAB activity.

Bacteria may accelerate the oxidation and precipitation of iron before it reaches sampling ports outside the well. Wells in this study that contained high levels of IRB, SRB and HAB activity had a median iron level of 1.58 mg/L lower than the median iron level of all wells tested. Iron bacteria can accelerate the oxidation of ferrous iron leading to the formation of ferric iron which tends to settle out and become part of the biofilm in the well or pipeline. This may explain the low levels of iron in the water samples that contain high levels of microbiological activity.

Shallow wells located in areas with silty or sandy near-surface deposits are more susceptible to nitrate contamination. The nitrate analyses revealed that 40 per cent of the wells had nitrate levels of 10 mg/L or greater, and ten (18%) of the wells exceeded the provincial guidelines of 45 mg/L. All but one of the wells, with nitrate levels above 45 mg/L, were shallow wells (< 15 m), and were generally in silty to sandy surficial deposits.

The relatively low percentage (i.e. 30%) of treated wells clearly shows that well owners in the area do not recognize the benefits of preventative maintenance and treatment.

Wells with high levels of nutrients in the source water are at a greater risk of biofouling than wells with low levels of nutrients. The median level of DOC was 3.1 mg/L higher, in wells with high levels of IRB, SRB and HAB activity, than the median DOC level of all the tested wells. In addition, the samples with high IRB, SRB and HAB activity have a median nitrate level that is 64.25 mg/L higher than the overall median nitrate level. Further research is required to provide a better understanding of the impact that these parameters have on microbiological activity in the water well environment.

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