TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

EXECUTIVE SUMMARY

The Sustainable Water Well Initiative (SWWI) was created by the Prairie Farm Rehabilitation Administration (PFRA) to address the deterioration of yield and water quality in water wells. Initial studies performed under the SWWI have shown that water well biofouling is a common problem faced by many well owners and that traditional acid treatments are often ineffective when applied to a well that has become plugged. As part of SWWI, PFRA-Technical Service is conducting a laboratory evaluation of various treatment processes for biofouled wells. Applied research projects are also being undertaken to field test and evaluate the effectiveness of these various treatment processes. The information gathered from these studies will be used to provide improved advice on methods to monitor, maintain and treat rural water wells.

The Town of Qu'Appelle Well Treatment Evaluation Project was initiated as an applied research project, under the SWWI. Traditional well rehabilitation techniques, undertaken by the Town of Qu'Appelle, had failed to improve the yield at one of their well sites (Well 5). In response to their request for assistance, PFRA agreed to work in partnership with the Town of Qu'Appelle to evaluate and field test an experimental well treatment process. Preliminary diagnostic work indicated that Well 5 was severely biofouled and had experienced an 84% decline in specific capacity since its installation in 1989. Microbiological testing, using Biological Activity Reaction Tests (BART^{TM}), indicated that there were highly aggressive populations of iron-related (IRB) and sulphate-reducing (SRB) bacteria present. The activities of these nuisance bacteria are known to lead to aquifer plugging, such as experienced around Well 5. In order to evaluate the ability of various treatment chemicals to remove aquifer plugging material, and thereby, improve aquifer permeability, small-scale laboratory testing was conducted at the PFRA Technology Adaptation Facility in Regina with permeameters containing aquifer samples collected in vicinity of Well 5. Based on these permeameter tests, a heat-activated treatment process was selected to be field tested at Well 5, in order to compare the field test results to the laboratory findings.

The treatment and redevelopment work at Well 5 was conducted from June 28-30, 1999. The well treatment was applied by PFRA and the redevelopment work was conducted by Hwy One Drilling Ltd. of Qu'Appelle, Saskatchewan. This well treatment proved to be more effective than the previous well rehabilitation efforts, increasing the specific capacity of Well 5 from 2.5 to 6.5 igpm/ft (imperial gallons per minute per foot) of drawdown. BART^{TM} analyses conducted after treatment indicate that high biological aggressivity levels still persist around the well. These results suggest that the biofilms and other accumulates that were plugging the void spaces of the aquifer were removed sufficiently to open pathways for water to more effectively enter the well. However, experience has shown that in the case of incomplete removal of the plugging material, the bacterial regrowth potential is high and preventative maintenance procedures must be implemented to maintain the well yield (PFRA and DBI, 1999; Keevill, March 1999).

Since the aquifer still appears to be significantly plugged, a regular monitoring schedule should be implemented and preventative maintenance procedures should be developed at the earliest opportunity. Water chemistry and biological analysis, and periodic pump tests should also be conducted to observe any changes in water quality and well capacity. These diagnostic procedures will assist in determining if further biological plugging is occurring around the well, and will signal the need for remedial action. Post treatment diagnostic testing conducted five months after treatment already indicate that IRB levels have returned to pre-treatment levels and emphasize the immediate need for a preventative maintenance strategy at Well 5. It is also

recommended that the Town of Qu'Appelle consider Well 5 as a potential applied research site to evaluate various preventative maintenance procedures.

ACKNOWLEDGEMENTS

Project Partners:

Town of Qu'Appelle:
The support and contributions to this project by the Town of Qu'Appelle are gratefully acknowledged. Also, special thanks to Bruce Betteridge and Bert Wickenheiser for their cooperation and assistance in the field.

Hwy One Drilling Limited :
A special thanks to Wes Maley of Hwy One Drilling Ltd. for his support and cooperation during the course of this project.

1.0 BACKGROUND

The deterioration of well yield and water quality is a concern to individuals, small communities and industries who rely on water wells as their principal source of water, and extending well life can result in significant savings in water supply costs. The Sustainable Water Well Initiative (SWWI) was created in 1996 by the Prairie Farm Rehabilitation Administration (PFRA), to address concerns of declining well yield, water quality deterioration and reduced well lifespan. The goal of the SWWI is to provide improved advice on the diagnosis, prevention and rehabilitation of well problems. Many of the physical and chemical problems that occur in water wells can be solved by well-established diagnostic and rehabilitation techniques. However, the microbiological aspects of water well deterioration and rehabilitation are still the least understood. Therefore, the SWWI has initially focused on this aspect of water well deterioration.

Past studies performed under SWWI have shown that water well biofouling is a common problem faced by well owners and that traditional acid treatments are often ineffective when applied to a well that has become severely plugged. This emphasized the need to evaluate some new and innovative well treatment methods currently available for biofouled wells, such as the Ultra Acid-Base™ (UAB™) treatment (PFRA and DBI, 1997). As part of SWWI, PFRA-Technical Service is also conducting laboratory testing on various treatment processes to evaluate their effectiveness, as well as performing field tests on selected biofouled wells to validate laboratory results. The information gathered from the laboratory and field testing will then be used to provide improved advice on methods that are used to monitor, maintain and treat rural water wells.

1.1 Introduction

In the spring of 1999, the Town of Qu'Appelle noticed a decline in yield from Well 5. As a result, Mr. Wes Maley of Hwy One Drilling Ltd. was contracted by the town to conduct any necessary well rehabilitation work. Prior to the well rehabilitation work, Well 5 had a reported yield of about 60 to 70 imperial gallons per minute (igpm). After an acid treatment and redevelopment of the well by Hwy One Drilling Ltd., Mr. Maley reported no appreciable increase in yield. On behalf of the town, Mr. Maley then contacted PFRA for assistance in dealing with this deterioration in well yield.

On May 3, 1999, diagnostic work, conducted jointly by Hwy One Drilling Ltd. and PFRA, revealed that Well 5 is biofouled and has experienced an 84% decline in specific capacity since its installation in 1989. On May 21, 1999, a meeting was held with the town to discuss the results of the diagnostic work. As a result of this meeting, an investigational plan was set out, and agreed to, where PFRA would work jointly with the Town of Qu'Appelle and Hwy One Drilling Ltd. to field test and evaluate a treatment process for biofouled wells.

As part of this investigation, PFRA was to first drill a test hole into the aquifer to collect a representative aquifer sample for laboratory testing purposes. Based on the results of the laboratory experimentation by PFRA, the treatment process would be designed for the aquifer conditions encountered at Well 5. PFRA would then proceed to field test the well treatment process and Hwy One Drilling Ltd. would conduct the redevelopment work. PFRA would conclude the project with some post treatment testing and monitoring to evaluate the effectiveness of the treatment process.

1.1 Historical Data

Well 5 was installed in November 1989, and is located about 10.5 kilometres west of the Town of Qu'Appelle, in LSD 7-20-18-15 W2 (see Figure 1). The well is completed in an unconfined aquifer, which consists of poorly sorted sand, gravel and boulders (Beckie, 1980). The well is completed to a depth of 13.4 metres below ground, and is situated in a pump house that is constructed on a concrete pad, about 2 metres above ground. The well consists of a 254 mm (10-inch) diameter steel well casing, with a 3-metre length of 25-slot (0.025 inch opening) stainless steel wire-wrapped screen attached to the casing, as shown in Appendix A. Four 5-centimetre (2-inch) diameter piezometers are located at various distances from Well 5 and can be used to monitor aquifer water levels. Well 4 is completed about 40 metres east of Well 5, and is used conjunctively with Well 5 to provide the water supply needs of the town.

The initial pump test conducted by International Water Supply Ltd. (IWS) in 1989 indicates that Well 5 had an original specific capacity of 15.4 igpm/ft of drawdown, at a pumping rate of 220 igpm. The original water analysis indicates that the water quality is relatively good, with a total dissolved solids of 809 mg/L. However, the iron and manganese levels were reported to be high (see Table 1). No pump tests have been performed on the well since its installation, and no previous well rehabilitation work has been conducted prior to 1999.

2.0 DIAGNOSTIC PROCEDURES AND RESULTS

The purpose of the diagnostic work is to determine the cause for the reduction in well yield, in order that an appropriate well treatment process can be designed for Well 5. To evaluate the condition of Well 5, a number of diagnostics procedures were performed. These investigative procedures included a down hole camera inspection of the well, a pump test, water chemistry and microbiological analysis, and the collection of aquifer samples for laboratory experimentation. The results of these procedures are provided in the following sections.

2.1 Down Hole Camera Inspection

On May 3, 1999, a down hole video camera inspection was conducted by PFRA. The down hole camera was lowered through the entire length of the well casing and screen and revealed that the well casing is in relatively good condition, with the presence of biological growths increasing at a depth of about 6 metres below the top of the casing. The well screen is relatively clean with some growths observed in the slots of the screen. The well had been previously acid-treated, and therefore, any incrustations or biological growths on the interior of the screen were probably removed. A copy of the down hole video was provided to the Town of Qu'Appelle.

2.2 Pump Testing

On May 3, 1999, a 90-minute pump test was conducted on Well 5 to determine its specific capacity and to collect water samples for chemical and microbiological analysis.

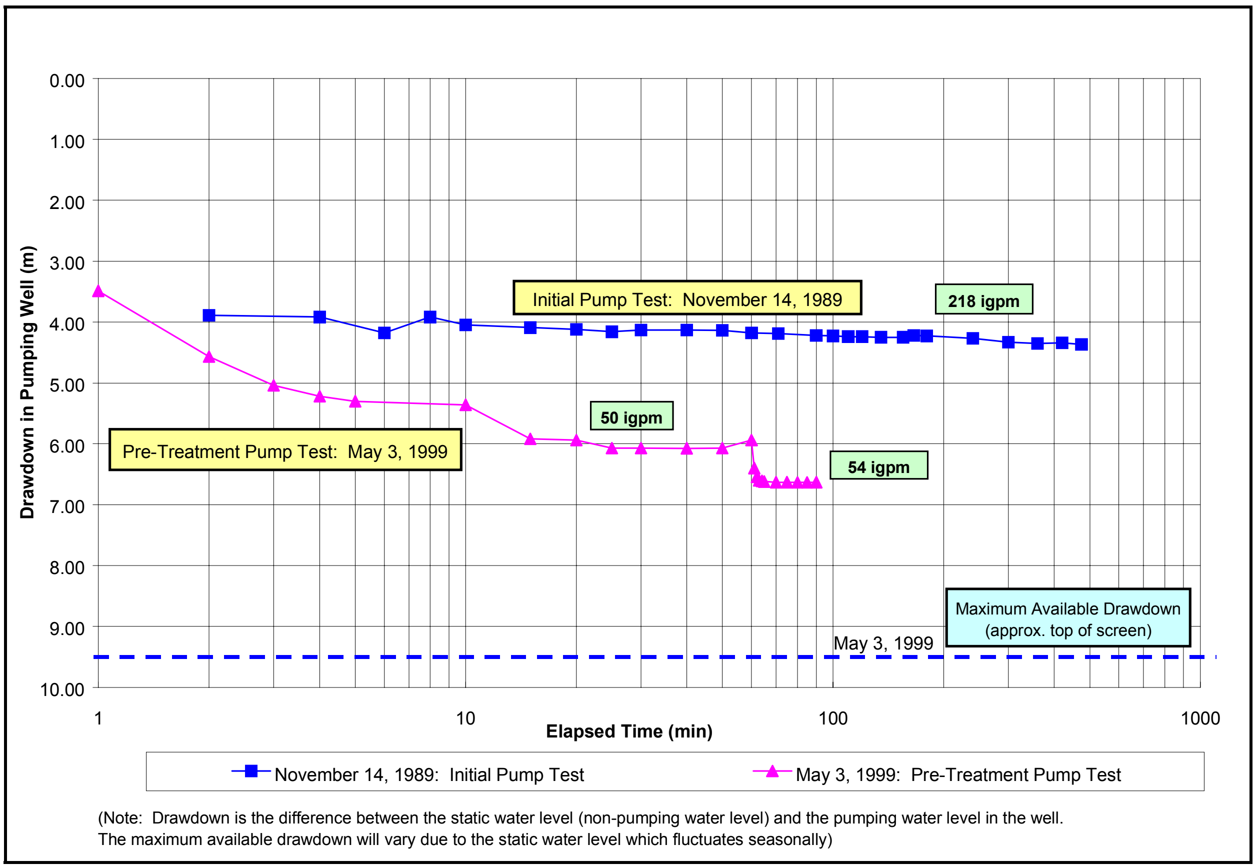


FIGURE 2 **Well 5: Pre-Treatment Pump Test**

During this pump test, water was pumped from the well at a constant rate and the water level was recorded at regular time intervals. The pump test results were compared to the original pump test data to determine the amount of well yield reduction experienced over the past 10 years (see Figure 2). The pump test results indicate that the specific capacity of Well 5 is 2.5 igpm/ft of drawdown, a decline of about 84% from the original specific capacity of 15.4 igpm/ft of drawdown (see Figure 3).

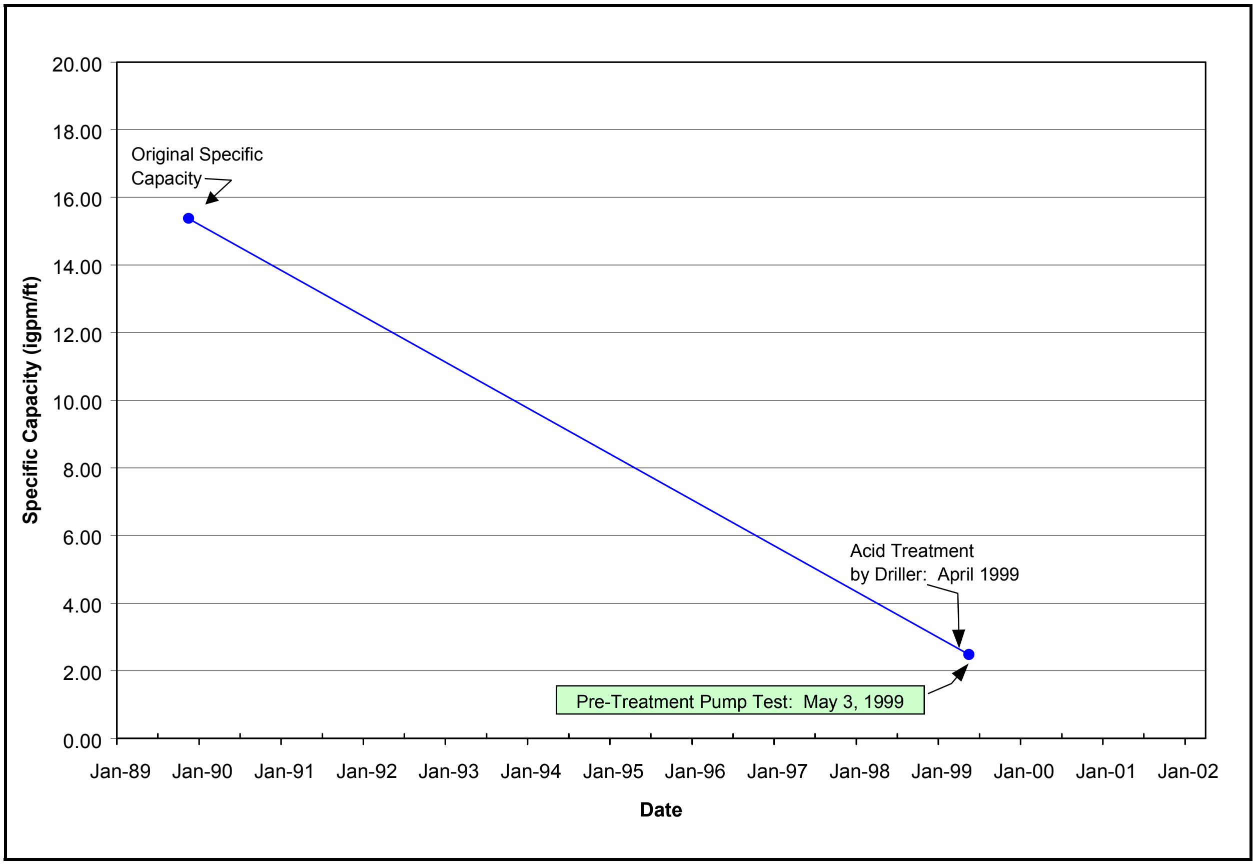


FIGURE 3 **Well 5: Pre-Treatment Specific Capacity Measurements**

2.3 Water Chemistry

At the end of the pump test conducted on May 3, 1999, a water sample was collected for chemical analysis. When compared to the original water analysis from November 15, 1989, test results show that there has been a deterioration in the water quality, with the total dissolved solids (TDS) level increasing from 809 mg/L to 1020 mg/L. One possibility for this increase in TDS is that poorer quality water from other areas of the aquifer has been diverted to the well over long-term pumping. After the Well 5 treatment, another water sample will be collected and analyzed for comparison purposes.

Based on the recent water analysis results, shown in Table 1, the overall water is still relatively good, with a total dissolved solids of 1020 mg/L. The water is considered extremely hard, with a calculated hardness of 683 mg/L. Therefore, unless softened, the water may be undesirable for some domestic uses.

Water Chemistry Parameter	Well 5 November 20, 1989	Well 5 May 3, 1999	Recommended Acceptable Limits
pH	-	7.4	6.5-9.0
Iron (mg/L)	5.2	5.4	0.3
Manganese (mg/L)	0.3	0.51	0.05
Nitrate (mg/L)	0.27	4	45
Sulphate (mg/L)	206	289	500
Calcium (mg/L)	111	148	200
Magnesium (mg/L)	48	76	150
Chloride (mg/L)	8	10	250
Bicarbonate (mg/L)	404	472	700
Total Hardness (mg/L $CaCO_3$)	475	683	100
Total Alkalinity (mg/L $CaCO_3$)	331	387	500
Total Organic Carbon (mg/L)	5.3	6.5 *	3
Total Dissolved Solids (mg/L)	809	1020	1000-1500

* sample taken July 18, 1999

TABLE 1 Well 5: Pre-Treatment Water Chemistry

Over the last ten years, nitrate levels have increased from 0.27 mg/L to 4 mg/L, as shown in Table 1. This increase in nitrate levels indicates that this unconfined aquifer is susceptible to contamination from surface sources, and protection from any surface contaminants is essential in maintaining a reliable water supply. Nitrates are also a source of nutrients that can promote the growth of nuisance bacteria which plug the pore spaces of the aquifer and cause a deterioration of both well yield and water quality. Iron and manganese concentrations in the water are at levels which can cause incrustations to form on the well casing and screen. As shown in Table 1, iron levels in both of the water analyses are greater than 5 mg/L, which not only produces significant staining, but can also promote the growth of iron bacteria. Another water quality parameter to note is the total organic carbon (TOC). Although the TOC content in the groundwater has not increased substantially since the installation of Well 5, this level of TOC may cause some problems in the treatment process. For instance, the presence of elevated TOC can cause iron and manganese to become more resistant to oxidation, making it more difficult to remove them from the water.

2.4 Microbiological Testing

The purpose of the microbiological testing is to determine the degree of biological activity in a well and surrounding aquifer. The results of these tests can also be used to evaluate the effectiveness of any subsequent well rehabilitation work, since these tests can be repeated once the well rehabilitation is completed. The analyses for bacterial activity were conducted using Biological Activity Reaction Tests (BART™s), which determine the presence and aggressivity of bacteria that promote biofouling problems. The specific BART™s used for the microbiological testing of the water were the IRB-BART™ (for iron related bacteria), the SRB-BART™ (for sulphate reducing bacteria), and the HAB-BART™ (for heterotrophic bacteria). A generalized summary of the results is shown in Table 2, and a more detailed description and interpretation of the test results and procedures is provided in Appendix B.

BART™ Test	Bacterial Aggressivity		
	10 minutes	30 minutes	60 minutes
Iron Related Bacteria (IRB)	High	High	High
Sulphate Reducing Bacteria (SRB)	High	High	High
Heterotrophic Bacteria (HAB)	High	High	Med

TABLE 2 Microbiological Aggressivity Levels: Pre-Treatment

On May 3, 1999, water samples for microbiological analysis were collected at 10, 30, and 60 minutes during a 90-minute pump test on Well 5. The water samples were collected in sterile containers and kept cool until they were added to the biodetectors in the laboratory. The BART™ tests were initiated on the same day the samples were collected. The test results from each of the water samples indicate that highly aggressive populations of Iron Related Bacteria (IRB) and Sulphate Reducing Bacteria (SRB) were present. Heterotrophic Aerobic Bacteria (HAB) were also highly aggressive, but showed medium aggressivity in the 60-minute sample. These results indicate that presence of high bacterial aggressivity levels in the well and surrounding aquifer. Based on these findings, Well 5 appears to be severely biofouled, and a treatment process designed to remove the biofilms that are plugging the void spaces in the aquifer is required to improve the well yield.

2.5 Drilling and Aquifer Sampling

The purpose of the drilling and aquifer sampling was to collect aquifer samples for microbiological analysis and for laboratory experimentation. A test hole was drilled by PFRA with a cable tool rig, approximately 3 metres south of Well 5. The intent was to drill the test hole to a depth of 13.4 metres, which represents the bottom of the 3-metre screen interval of Well 5. Aquifer samples would be collected at random intervals above the screen interval for classification purposes and grain-size analysis, and once the screen interval was encountered, aquifer samples would be collected for detailed laboratory analysis.

The test hole drilling took place from May 25-27, 1999, and the test hole (C-1) was completed to a depth of about 12 metres. Due to time constraints, C-1 was not completed to its anticipated depth of 13.4 metres, and the 100 mm (4-inch) diameter drive casing was left in place in order to complete this test hole at a later date. Grain-size analyses were performed by PFRA on the aquifer samples collected from various depths and the aquifer material collected from 10.3 to 12 metres was also used by PFRA for laboratory experimentation. On October 6, 1999, C-1 was completed to a depth of 13.9 metres and a 50 mm (2-inch) diameter PVC piezometer was installed. The grain-size analysis results, test hole log and piezometer construction details are included in Appendix C.

3.0 WELL TREATMENT

As part of SWWI, PFRA-Technical Service is conducting an evaluation of various well treatment chemicals and treatment processes designed for biofouled wells, at the PFRA Technology Adapation Facility in Regina. Joint venture partnerships are also being pursued with well owners and the water well industry to evaluate the effectiveness of these treatment processes at biofouled well sites, and then to compare these findings to laboratory test results. To date, the findings from ongoing laboratory studies generally reinforce the concept that increasing the temperature of treatment chemical solutions increases the dissolution and removal of material, thereby, resulting in an increase in the permeability of the aquifer material (PFRA and DBI, 1999).

In order to evaluate the effects of various treatment chemicals and treatment processes on aquifer permeability, a small-scale test cell, known as a permeameter, is being used in the laboratory. Biofouled aquifer material is placed into the permeameter and various treatment chemicals are tested at different concentrations and temperatures. The sequencing of these chemicals as part of a treatment process is also being evaluated. As well, swell-consolidation tests are being conducted to measure the swelling potential of various well treatment chemicals on clay particles that may be present in aquifers. Laboratory experimentation by PFRA has previously been conducted on several commercially-available chemicals commonly used in well rehabilitation (Stewart, 1998). Current laboratory protocols are patterned after those used by PFRA and Droycon Bioconcepts Inc. (DBI) of Regina, Saskatchewan, to further evaluate the UAB™ treatment process field tested as part of the City of North Battleford Well Rehabilitation Project (PFRA and DBI, 1999; Keevill, March 1999).

3.1 Well 5 Treatment Process

In order to validate the results from ongoing PFRA laboratory studies on the effectiveness of various treatment chemicals and treatment processes, a joint venture agreement was reached between the Town of Qu'Appelle and Hwy One Drilling Ltd. to field test and evaluate a treatment approach for Well 5. Based on the results of laboratory testing, a heat-activated treatment, consisting of three distinct stages, was selected for the field test at Well 5.

The first stage of the treatment was designed to penetrate the biofilms and mobilize any clay-size particles in the aquifer. The first stage included the following steps. First, 1000 litres of hot water were added to pre-heat the well. Then, a solution containing 3500 litres of hot water and 35 litres of a proprietary surfactant were added. This solution raised the pH in the well to about 8.5. After this step, the well was surged with air, pumped clean and a pump test was conducted. The pump was then removed prior to the second stage of treatment.

The second stage of the treatment was designed to break-up the biofilms and any other accumulates surrounding the well intake area. The second stage commenced by again pre-heating the well, with the introduction of 1000 litres of hot water. A 4000-litre solution of acetic acid (10% by volume) and hot water was then added. This acid solution lowered the pH to about 2.5-3.0, and the solution remained in the well overnight.

The third stage involved air surging and air-lift pumping to disperse and remove the biofilms along with the other associated plugging material from the aquifer. The well was then air-lift pumped until the water was clear and the pH had returned to its pre-treatment levels.

Also, a pre-treatment stage is often recommended to clean the well screen area, thereby, allowing a more effective penetration of treatment chemicals into the aquifer. A pre-treatment stage was not included for Well 5, since this well had previously been acid-treated and the down hole video camera inspection revealed that the inside of the screen was relatively clean.

3.2 Well Treatment Results

The Well 5 treatment was performed on June 28-30, 1999, according to the procedures outlined in section 3.1. On June 28th, after the surfactant solution had been pumped from the well, a pump test was conducted which revealed that the specific capacity of the well had improved from 2.5 to 3.0 igpm/ft, as shown in Figure 4. On June 29th, the acid solution was added and remained in the well overnight. Then, on June 30th, the biofilms and other plugging material were removed from the aquifer by air surging and air-lift pumping for about 9 hours. When this air-lift development period was completed, the water was pumping clean and the pH had stabilized at about 7.0. A submersible pump was then installed and a short pump test indicated that the specific capacity had improved to about 6.6 igpm/ft (see Figure 4).

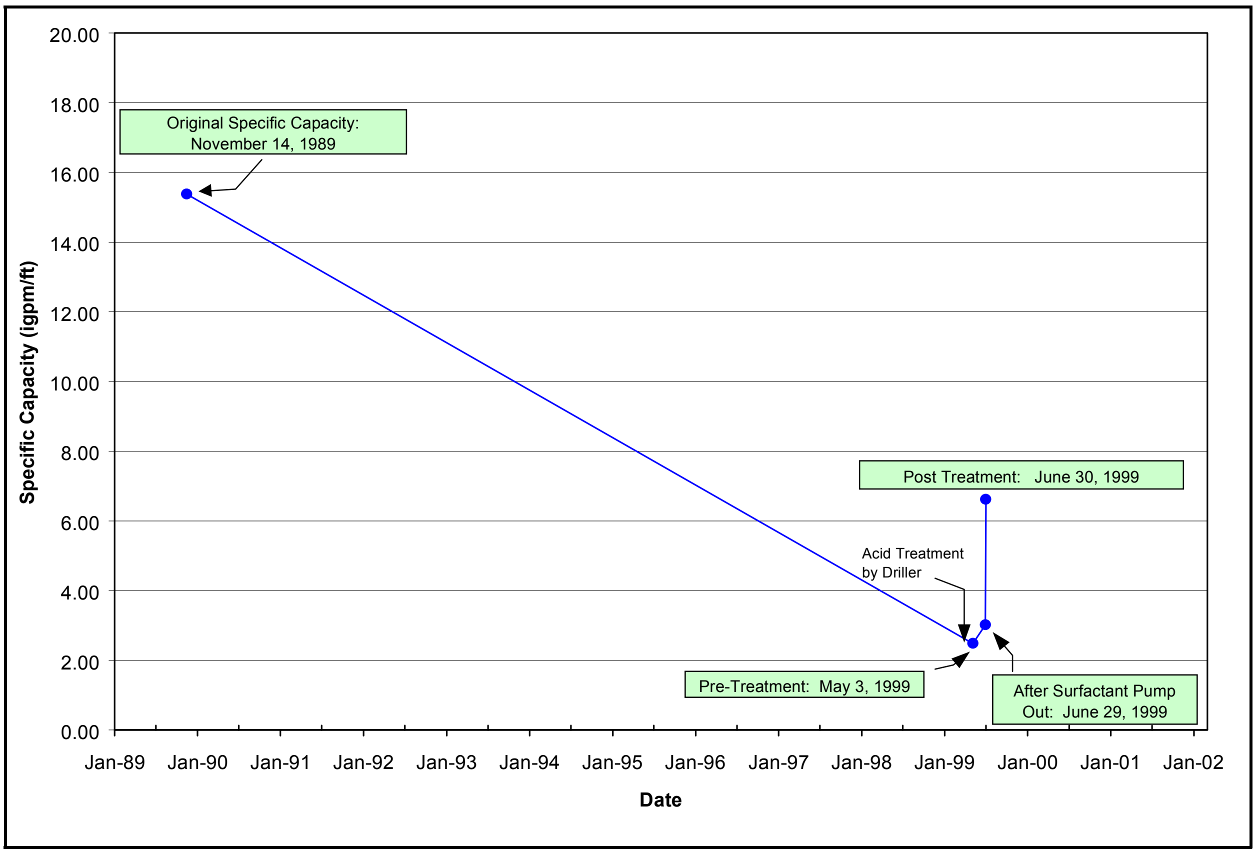


FIGURE 4 Well 5: Post Treatment Specific Capacity Measurements

On July 2-3, 1999, the well was air-lift pumped to ensure any remaining material was removed before reinstalling the Town pump. On July 6, 1999, the Town pump was reinstalled and a step drawdown test was conducted on July, 7, 1999. This pumping test consisted of four consecutive, 30-minute pumping intervals at 92, 118, 147 and 154 igpm, respectively. This step drawdown test confirmed that the specific capacity of the well had improved to about 6.5 igpm/ft. Three subsequent step drawdown tests were conducted on August 5, September 30, and November 17, 1999, in order to obtain post treatment water samples for microbiological and water chemistry analysis. The results from these post treatment pumping tests indicate that there has been no decrease in the specific capacity of Well 5 since treatment, as shown in Figure 5. The detailed results of all these pump tests are provided in Appendix A.

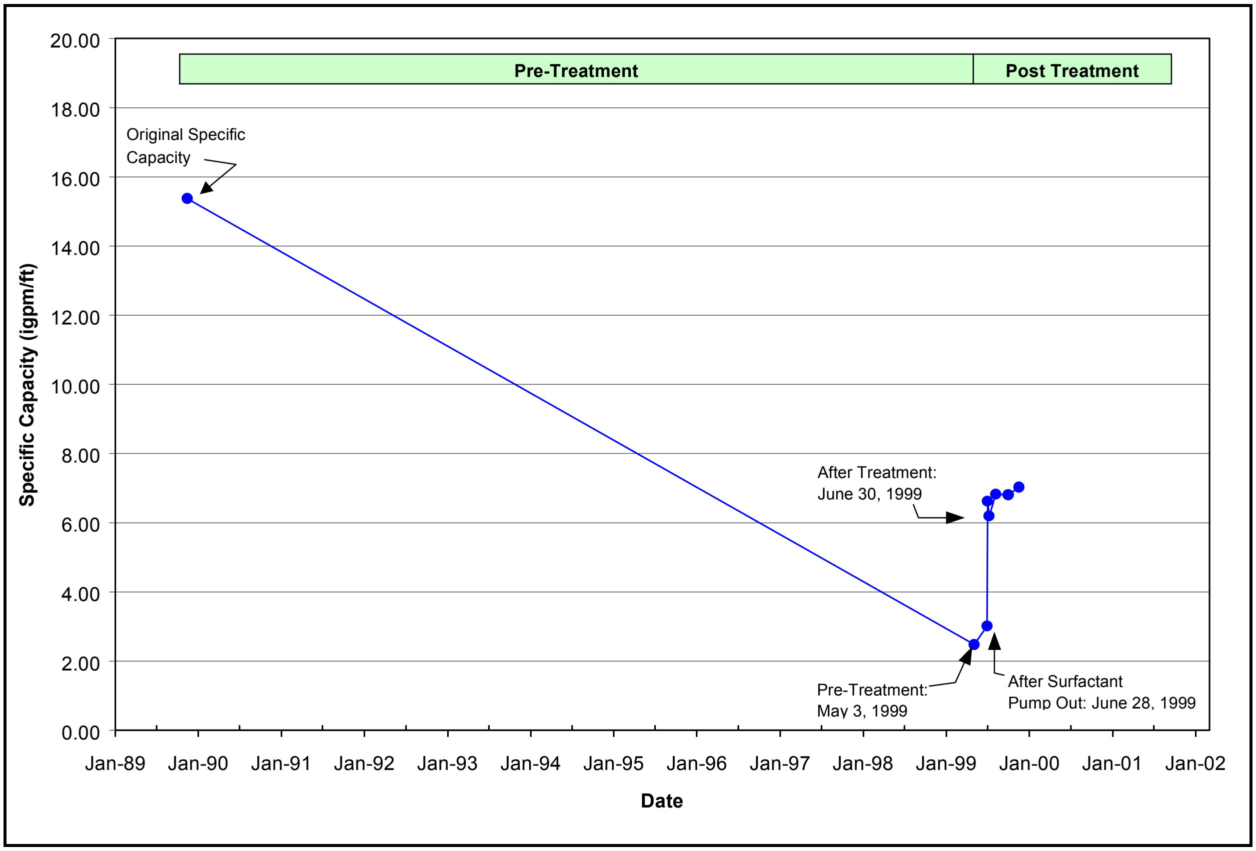


FIGURE 5 **Well 5: Specific Capacity Measurements**

During the post treatment pump tests, a water sample for water chemistry analysis was collected after one-hour of pumping. As shown in Table 3, the post treatment water chemistry analyses obtained over the five months since the well treatment was applied, indicates that the overall water quality is comparable to pre-treatment conditions.

Water Chemistry Parameter	Pre-Treatment	Post Treatment			Recommended Acceptable Limits
	May 3, 1999	Aug. 5/99	Sept. 30/99	Nov. 17/99	
pH	7.4	7.1	7.2	7.1	6.5-9.0
Iron (mg/L)	5.4	3.6	4.8	3.3	0.3
Manganese (mg/L)	0.51	0.5	0.61	0.51	0.05
Nitrate (mg/L)	4	<1	<1	<1	45
Sulphate (mg/L)	289	306	395	299	500
Calcium (mg/L)	148	141	173	154	200
Magnesium (mg/L)	76	73	96	76	150
Chloride (mg/L)	10	8	12	12	250
Bicarbonate (mg/L)	472	459	537	481	700
Total Hardness (mg/L $CaCO_3$)	683	653	827	698	100
Total Alkalinity (mg/L $CaCO_3$)	387	376	440	394	500
Total Dissolved Solids (mg/L)	1020	1008	1240	1043	1000-1500

TABLE 3 **Well 5: Water Chemistry Comparisons**

A deterioration in the overall water quality was observed in the September 30, 1999, water analysis results. However, this may be due to the fact that the well had not been pumped regularly over the previous two months and the water was being withdrawn directly from the surrounding aquifer, with little influence from the better quality water that is usually induced from nearby Happy Valley Lake. At this time, the reasons for the changes in the overall water quality are not well understood and ongoing water quality monitoring is recommended to evaluate the significance of these water quality changes.

One parameter that has shown a significant reduction is the nitrate level. After treatment, the nitrate levels were reduced from 4 mg/L to less than 1 mg/L (see Table 3). The reason for this reduced nitrate level is not known, since sufficient data is not available to make a detailed interpretation. It is possible that the pre-treatment nitrate level, measured on May 3, 1999, is the result of a spring recharge or flow-through event in the aquifer, which would naturally dissipate with time. Since a water sample was not taken just prior to treatment, it is not known if the nitrate level had already diminished to less than 1 mg/L. The oxidation and reduction of nitrogen compounds by microbiological activity could also affect nitrate levels around the well. Therefore, there are several factors that could affect the nitrate levels measured from the well, and more detailed monitoring of both nitrate levels and biological activity is required to provide a better understanding of the effects of biological activity and nitrate levels in the aquifer.

Water samples for microbiological analysis were also collected at 10, 30 and 60 minutes. The microbiological analyses using the BART™s indicate highly aggressive populations of HAB, IRB and SRB present around the well. These results reveal that the high bacterial levels measured prior to treatment are still present. Although a reduction in the aggressivity of IRB was measured on September 30, 1999, the IRB reached high aggressivity levels by November 17, 1999. The reduction in IRB population may be a result of the general inactivity of Well 5 from August until November 1999. It appears that once regular pumping of the well commenced in early November 1999, the IRB population increased. Detailed BART™ results are presented in Appendix B.

BART™	IRB			SRB			HAB		
Sample Time (min)	Post Treatment Aggressivity			Post Treatment Aggressivity			Post Treatment Aggressivity		
	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99
10	High	Med	High	High	High	High	High	Med	Med
30	High	Med	High	High	High	High	High	Med	Med
60	High	Med	High	High	High	High	Med	Med	Low

TABLE 4 Microbiological Aggressivity Levels: Post Treatment

3.2.1 Discussion of Well Treatment Results

The well treatment and rehabilitation work on Well 5 proved to be more effective than previous well rehabilitation efforts, increasing the specific capacity of the well from 2.5 to 6.5 igpm/ft of drawdown. However, BART™ analyses conducted after treatment indicate that the biological aggressivity after treatment is generally similar to pre-treatment levels. These results suggest that the biofilms that were plugging the void spaces of the aquifer were removed sufficiently to open pathways for water to more effectively enter the well.

However, the aquifer still appears to be significantly plugged with biofouling material, and the biological activity is still relatively high.

Results from similar field tests of treatment processes indicate that biofouled wells that have experienced a specific capacity decline of more than 40 percent are often difficult to restore to their original specific capacity (PFRA and DBI, 1999; Keevill, March 1999). These study results emphasize the necessity of implementing a diligent monitoring program to reduce the risk of premature well failure. Also, since Well 4 is situated within 40 metres of Well 5, preliminary diagnostic work should be conducted to determine its overall condition and performance characteristics.

In order to reduce the potential for a decline in the specific capacity at Well 5, a regular monitoring schedule should be implemented and preventative maintenance procedures should be developed and at the earliest opportunity. As part of the SWWI, PFRA-Technical Service is currently evaluating preventative maintenance treatments in the laboratory, and the results from these lab-scale investigations could then be field tested at Well 5 to assist the Town of Qu'Appelle with the design of a preventative maintenance strategy. It is, therefore, recommended that the town consider continuing their partnership with PFRA, to evaluate and field test potential preventative maintenance procedures for Well 5.

Ongoing water chemistry and biological analysis should also be conducted to observe any changes in water quality, and periodic pump tests should be performed to measure the specific capacity of Well 5. These diagnostic procedures will assist in determining if any further biological plugging is occurring around the well, and when preventative maintenance procedures should be implemented.

4.0 CONCLUSIONS

1. Well 5 has experienced an increase in specific capacity, from 2.5 to 6.5 igpm/ft, as a result of the well treatment process.

2. Based on the BART™ results, Well 5 is severely biofouled. Although the specific capacity of Well 5 has improved after treatment, the biological activity in the immediate vicinity of the well is still highly aggressive.

3. Since its installation in November 1989, Well 5 has experienced a deterioration in overall water quality, with an increase in total dissolved solids (TDS) levels from 809 mg/L to 1020 mg/L.

4. Since 1989, nitrate levels have increased from 0.27 mg/L to 4 mg/L. This increase in nitrate levels suggests that this unconfined aquifer is susceptible to contamination from surface sources, and protection from any surface contaminants is essential in maintaining a reliable water supply. Nitrate is also a nutrient that can promote the growth of nuisance bacteria present around Well 5. After treatment, nitrate levels were reduced to less than 1 mg/L. More detailed monitoring of both nitrate levels and biological activity is required to provide a better understanding of the effects of biological activity and nitrate levels in the aquifer.

5. Iron and manganese concentrations are above the recommended drinking water guidelines, which can result in incrustations to be deposited on the well casing and screen, and within the distribution system. These elevated iron levels can also enhance the growth of iron bacteria in the well and surrounding aquifer, as well as in the distribution system.

6. The total organic carbon (TOC) content in vicinity of Well 5 has increased slightly over the past ten years, from 5.3 to 6.5 mg/L. This level of TOC may cause some problems with the town's treatment process.

5.0 RECOMMENDATIONS

1. Based on the well treatment results, it is recommended that any future well treatments for Well 5 be designed to deal with the biofouled condition surrounding this well.

2. Based on the post treatment pump test results, Well 5 has a potential pumping capacity of about 180 igpm, depending on the available drawdown. However, it is recommended that Well 5 be pumped continuously at a reduced pumping rate of about 100 igpm. Pumping the well at a reduced rate should reduce its plugging potential.

3. In order to reduce the potential for a future decline in specific capacity, it is recommended that a regular monitoring schedule and preventative maintenance procedures (PM) be developed and implemented at the earliest opportunity.

4. To assist the Town of Qu'Appelle in developing a preventative maintenance strategy for Well 5, it is recommended that the town consider extending the partnership established with PFRA to complete the current Well Treatment Evaluation Project, to include the evaluation and field testing of various preventative maintenance procedures.

5. Ongoing water chemistry and microbiological analysis, and periodic pump testing are recommended to observe any changes in water quality and well capacity, since these diagnostic procedures will indicate if further biological plugging is occurring.

6. Since Well 4 is located only 40 metres from Well 5, it is recommended that preliminary diagnostic work also be conducted on this well to determine its condition and performance characteristics.

7. The presence of elevated total organic carbon (TOC) can cause problems with the town's water treatment process. Therefore, it is recommended that a water treatment specialist be contacted to determine if any potential problems could arise.

6.0 REFERENCES

Beckie, V., Famulak, M., 1980. *Report on Well Installation Program for the Town of Qu'Appelle.* Beckie Hydrogeologists Limited, Regina, Saskatchewan.

Keevill, B., 1999. *City of North Battleford Well Rehabilitation Project, Phase 1 Well Diagnostics (Biological and Chemical).* March 1999. Droycon Bioconcepts Incorporated, Regina, Saskatchewan.

Keevill, B., 1999. *City of North Battleford Well Rehabilitation Project, Phase 2 Well Rehabilitation (Ultra Acid-Base™ Treatment).* December 1999. Droycon Bioconcepts Incorporated, Regina, Saskatchewan.

PFRA and DBI, 1997. *Development of Ultra Acid-Base (UAB™) Water Well Treatment Technology.* Prairie Farm Rehabilitation Administration and Droycon Bioconcepts Incorporated.

PFRA and DBI, 1998. *City of North Battleford Well 15, 1997 Field Test of UAB™ Water Well Treatment Technology.* Prairie Farm Rehabilitation Administration, Earth Sciences Unit.

PFRA and DBI, 1999. *City of North Battleford Well Rehabilitation Project, Phase 1: Well Diagnostics Program.* Prairie Farm Rehabilitation Administration, Earth Sciences Unit.

PFRA, 1999. *Town of Qu'Appelle Well Treatment Evaluation, Interim Report.* Prairie Farm Rehabilitation Administration, Earth Sciences Unit.

Sawyer, C.N., Mc Carty, P.L., Parkin, G.F., 1994. *Chemistry for Environmental Engineering, Fourth Edition.* McGraw-Hill Inc.

Toth, A. M., 1990. *Town of Qu'Appelle, Saskatchewan, Hydrogeological Engineering Report Qu'Appelle's Well Water Supply.* International Water Supply Limited.

Microbiological Analysis
Town of Qu'Appelle: Well 5

1) Microbiological Analysis Using The BART™ System

The Biological Activity Reaction Test (BART™) system offers a simple method for detecting the presence and aggressivity of selected groups of nuisance bacteria that are often involved in the biofouling of a water well. There are seven different tests that are recognizable by colored cap coding. These include selective tests for:

Iron Related Bacteria	IRB-BART™	Red Cap
Sulfate Reducing Bacteria	SRB-BART™	Black Cap
Heterotrophic Aerobic Bacteria	HAB-BART™	Blue Cap
Slime Forming Bacteria	SLYM-BART™	Green Cap
Denitrifying Bacteria	DN-ART™	Grey Cap
Nitrifying Bacteria	N-BART™	White Cap
Fluorescing Pseudomonads	FLOR-BART™	Yellow Cap

Often a combination of these tests are used to determine which group of bacteria are present and causing problems. The bacteria groups most commonly tested for when testing wells on the Prairies are the SRB, IRB and HAB.

2) Why Use a BART™ Test?

The simplicity and unique nature of the BART™ test make it very useful, and perhaps more effective then traditional agar techniques, in detecting the nuisance bacteria involved in well biofouling. The water used in the BART™ test comes directly from the sample which keeps the microbes within a fairly natural environment, whereas the water used in agar method comes tightly bound within the agar. In the agar method, microbes have to be taken from the water, placed into contact with the agar surfaces, and are expected to "mine" the bound water for growth. Many microbes are not able to easily do this and so may be missed using agar cultural techniques. In addition, the BART™ system provides a greater variety of environments within which a particular bacteria can grow. The plastic test vials contain a floating ball which restricts the amount of oxygen entering into the water sample below. This results in the formation of a reduction-oxidation gradient within the vial with a transitional zone (redox front) in the middle. This allows aerobic microbes to grow near the top of the vial, while anaerobic bacteria will tend to grow near the bottom. These environments have many of the characteristics of a water well and quite often the events observed in these biodetectors are similar to the events observed when a video-camera log is obtained for a well.

To encourage the activities and reactions of a specific group of microbes, the BART™ vials contain a crystallized deposit of selective nutrients, which sit in the bottom of the tube. These nutrients begin to dissolve and move slowly up the BART™ tube when the water sample is added. This slow upward progression, which can take as long as two days, gives the microbes in the sample time to adapt, grow and become active. Even the very sensitive microbes that would normally fail to grow on any agar media are better able to adapt and grow if the crystallized medium is suitable for their growth (1999, DBI BART™ Information Series).

3) **How to Use the BART™ s**

Two forms of data can be obtained by using this system: 1) the days of delay (DD) or time lag (TL) which is the time elapsed from the addition of water to the biodetectors until the initial reaction occurs and, 2) the reaction type (RX). The DD or TL are used to determine the level (e.g. high, medium, low) of aggressivity of a bacteria group. The shorter the days of delay for a reaction to occur, the more aggressive the bacteria. The various reactions observed provide an indication of the types of bacteria present in the water sample. (Cullimore, 1993. Practical Manual of Groundwater Microbiology).

When a water sample taken from a well contains highly aggressive populations of bacteria, it is an indication that there may be zones of biofouling in the well or in the aquifer which supplies water to the well. Smaller values of DD indicate more aggressive populations of bacteria. The following table is a summary of the data, supplied by Droycon Bioconcepts Inc., which is used as a guide to determine the aggressivity levels of SRB, IRB and HAB in a water sample.

Bacterial Aggressivity Level	DD Days to Initial Reaction in the IRB-BART™	DD Days to Initial Reaction in the SRB-BART™	DD Days to Initial Reaction in the HAB-BART™
High	1 - 4	1 - 6	1 - 2
Medium	5 - 8	7 - 8	3 - 4
Low	9 - 10	9 - 10	5 - 10

Table 1: Determining Bacterial Aggressivity Levels

(* Note: Field testing of the BART's over the period of 1995 to 1997 have led to some discrepancies in the interpretation of the time lag and level of aggressivity in the SRB-BART's. At this time it is not evident whether the shift from highly aggressive SRB to medium aggressivity occurs on the 5th, 6th, or 7th day of testing.)

A list of the possible reactions (RX) is included with the test kits or can be obtained from Droycon Bioconcepts Inc. Determining the bacterial aggressivity levels is a fairly simple procedure and is all that is required to determine if a well is biofouled. Whereas, identifying the specific types of bacteria involved in the reactions is difficult and generally requires some guidance.

In conducting these tests, it is important to test more than one sample from a well, since the number of microorganisms detected may vary from one sample to the next. Several factors contribute to this variance. First, biofouling generally occurs in an irregular fashion around a well, and therefore, water entering the well may not always pass through an area of biofouling. Also, biofilms tend to slough (break apart) as a result of pressure changes caused by pumping and this can cause microorganisms in the biofilms to be released into the water at random intervals. Collecting a number of samples as the well is pumped, ensures a more accurate representation of the extent of biofouling. In addition, water samples collected after pumping for a short time are likely to reflect the bacterial activity within the well or close to the well, whereas samples taken after an extended period of pumping are more likely to reflect the bacterial activity occurring in the aquifer beyond the immediate well intake.

4) BART™ Test Results: Well 5

On May 3, 1999, three water samples were collected for BART™ analysis, during a 90-minute pump test. These samples were collected after 10 min, 30 min and 60 min of pumping. The water samples were collected in sterile containers and kept cool until they were added to the biodetectors in the laboratory. Tests for SRB, IRB and HAB were performed on the water samples on the same day the samples were collected. The test results (DD and aggressivity levels) are listed in Tables 2 and 3.

BART™	IRB	SRB	HAB
Sample Time (min)	Pre-treatment DD	Pre-treatment DD	Pre-treatment DD
10	3	2	2
30	3	2	2
60	3	2	3

Table 2: BART™ Test Results - Days of Delay (DD) to First Reaction

BART™	IRB	SRB	HAB
Sample Time (min)	Pre-treatment Aggressivity	Pre-treatment Aggressivity	Pre-treatment Aggressivity
10	High	High	High
30	High	High	High
60	High	High	Med

Table 3: Levels of Microbiological Aggressivity

BART™ Data Interpretation:

BART™ tests performed on each of the water samples, taken from Well 5 on May 3, 1999, confirmed the presence of highly aggressive populations of Sulphate Reducing Bacteria (SRB) and Iron Related Bacteria (IRB). Heterotrophic Aerobic Bacteria (HAB) were highly aggressive in the samples taken after 10 and 30 minutes of pumping. HAB-BART™ tests performed on the water sample collected after 60 minutes of pumping showed only medium aggressivity. These results indicate that biofouling is occurring in this well or in the aquifer surrounding the well intake. A detailed description of well biofouling is also included as part of this appendix, in the section entitled, *Microbiological Activity and Water Well Deterioration.*

Post Treatment BART™: Well 5

On August 5, 1999, approximately one month after treatment, a pump test was conducted and three water samples were collected from Well 5 for microbiological analysis. These samples were collected after 10 min, 30 min and 60 min of pumping. The water samples were collected in sterile containers and kept cool until they were added to the biodetectors in the laboratory. Tests for SRB, IRB and HAB were performed on the water samples on the same day the samples were collected. Similar tests were also conducted on September 30, 1999 and November 17, 1999. The results of the post treatment BART™ analyses performed on Well 5 were compared to the pre-treatment levels, as shown in Tables 4 and 5.

BART™	IRB			SRB			HAB		
Sample Time (min)	Post Treatment DD			Post Treatment DD			Post Treatment DD		
	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99
10	3	5	3	2	2	3	2	4	4
30	4	5	2	2	2	2	2	4	4
60	4	5	2	2	2	3	3	4	5-6

Table 4: BART™ Test Results - Days of Delay (DD) to First Reaction

BART™	IRB			SRB			HAB		
Sample Time (min)	Post Treatment Aggressivity			Post Treatment Aggressivity			Post Treatment Aggressivity		
	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99	5/8/99	30/9/99	17/11/99
10	High	Med	High	High	High	High	High	Med	Med
30	High	Med	High	High	High	High	High	Med	Med
60	High	Med	High	High	High	High	Med	Med	Low

Table 5: Levels of Microbiological Aggressivity

BART™ Data Interpretation:

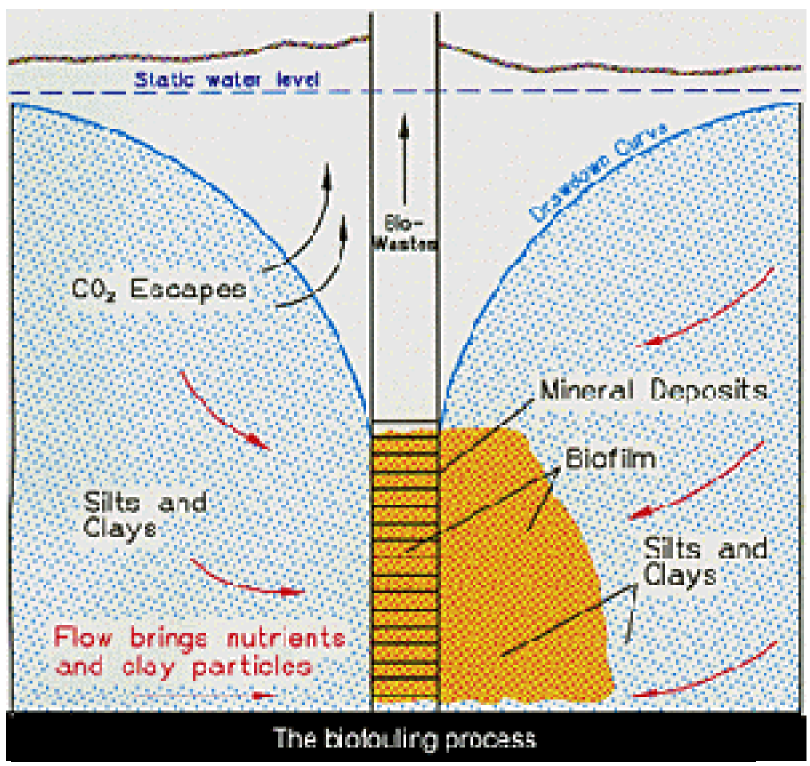
BART™ analyses results obtained from of the post treatment water samples confirm the presence of highly aggressive populations of Sulphate Reducing Bacteria (SRB) and Iron Related Bacteria (IRB). Heterotrophic Aerobic Bacteria (HAB), tested with the HAB-BART™, were initially highly aggressive, but by November 1999 indicated only medium aggressivity. Although the HAB population appears to have been reduced, the IRB and SRB populations indicate that biofouling is still severe in the aquifer surrounding the well intake. Further microbiological testing will be required to continue to monitor the biological activity around the well and forewarn of any potential biological plugging in the future.

Microbiological Activity and Water Well Deterioration

Water wells are the primary water source for most rural residents of Canada. Understanding the cause of water well deterioration and developing ways to sustain water well environments is important in maintaining and improving the quality of life in rural Canada. The deterioration of well yield and water quality is a concern to individuals, small communities and industries who rely on water wells as their principal source of water.

Currently, when the quality or quantity of water produced declines dramatically, wells are often 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 well owners. Correctly identifying the cause of water well problems offers the possibility of effective treatment and maintenance instead of well abandonment.

Losses in water well production and water quality have traditionally been attributed to the chemical and physical properties of the water well environment. Many of these problems can be solved by well-established diagnostic and rehabilitation techniques. However, less recognized is that groundwater contains microorganisms such as bacteria, and the activities associated with these microorganisms also cause significant water well problems.



The biofouling process

Water well deterioration caused by microbiological activity is termed biofouling. Installing and pumping a well increases the level of oxygen and nutrients in the well and in the surrounding aquifer. This encourages bacterial cells, which are naturally present in groundwater, to anchor themselves to surfaces in the well and around the well intake. Once attached these bacteria quickly multiply and colonize these surfaces. 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, forming biomasses (see Figure 1).

Some of the byproducts associated with bacterial growth, such as oxidized iron and manganese, will also become accumulated in these secretions. This leads to the production of the red or black slimes often found in toilet tanks or observed on pumps and discharge lines when they are pulled from a well. Biofouling of a water well occurs when biofilms accumulate a sufficient amount of debris to interfere with water flow and affect water quality.

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 and iron build-up in the well and distribution pipes, which leads to occasional discoloration of the well water. Biofouling can also result in the production of odours such as rotten egg or fishy smells, changes in taste, and corrosion of steel and iron casings and pipes. Once developed, a biomass can protect the bacterial cells from environmental changes like changes in pH, changes in temperature and fluid velocities, which makes treatment chemicals less effective and removal of plugging material more difficult. This emphasizes the importance of regular well maintenance.

There are a number of field and laboratory tests that can be used to monitor water quality and biological activity in groundwater. If performed on a regular basis, one month after the well is installed and then once every six months, these tests will indicate when water quality is changing or when biological activity is increasing.

Changes in water quality and increased levels of biological activity are an indication that well maintenance is required. Ideally, appropriate well maintenance chemicals should be applied before well performance is significantly affected. Establishing a monitoring schedule, where pumping water levels and well pumping rates are recorded, is also an effective way to identify when preventative maintenance measures are no longer effective and well rehabilitation is required.

Recently, a number of water well studies, directed by the Prairie Farm Rehabilitation Administration (PFRA), have been performed on the Canadian Prairies to address concerns of declining well yield and water quality deterioration. These studies have led to the creation of the Sustainable Water Well Initiative (SWWI). One of the goals 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 to well owners on the methods used to diagnose, prevent and treat well problems.

Past studies performed under SWWI have shown that water well biofouling is a common problem faced by well owners and that traditional well treatments, such as acid treatments, are often ineffective when applied to a well that has become significantly plugged.

Presently, a laboratory review and evaluation of well maintenance chemicals currently employed to restore well-aquifer efficiencies is being conducted by PFRA. In addition, field projects are under way to test the effectiveness of well rehabilitation technologies. The information gathered from these studies will be used to provide improved advice on the methods used to monitor, maintain and treat rural water wells.