Sustainable Water Well Initiative

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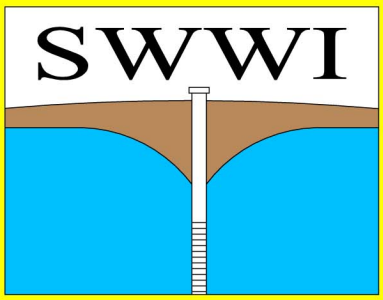

Town of Qu'Appelle: Well 5
Enzyme-Based Well Treatment Evaluation

Prepared by:
Earth Sciences Unit
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Agriculture and Agri-Food Canada
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Canada

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EXECUTIVE SUMMARY

A field evaluation of an enzyme-based well treatment process was conducted by the Prairie Farm Rehabilitation Administration (PFRA) in partnership with the Town of Qu'Appelle. This applied research project was initiated as part of PFRA's Sustainable Water Well Initiative (SWWI), to investigate new and innovative treatment approaches for biofouled water wells.

Traditional well treatment techniques, previously performed by the Town of Qu'Appelle, had failed to prevent the decline in yield at Well 5. Therefore, the Town expressed an interest in investigating alternate treatment and preventative maintenance methods for sustaining their water well supplies. In 1999, PFRA and the Town of Qu'Appelle field tested a heat-activated treatment process at Well 5 (PFRA, 1999). Prior to applying this treatment process, diagnostic testing indicated that Well 5 was biofouled and had experienced an 84% decline in specific capacity since its installation in 1989. After treatment, the specific capacity of Well 5 increased from 2.5 to 6.5 igpm/ft (imperial gallons per minute per foot) of drawdown, restoring the well to about 42% of its original specific capacity. Although this treatment process was more effective at removing the plugging material than previous well rehabilitation efforts, it was still not able to restore the well to its original specific capacity.

Subsequent laboratory experimentation conducted at the PFRA Technology Adaptation Facility in Regina, revealed that an enzyme-based treatment process also showed promise in improving the permeability of biofouled aquifer material. Therefore, in June, 2002, the Town of Qu'Appelle agreed to collaborate with PFRA to evaluate this alternative treatment method at Well 5. After this treatment was applied, the specific capacity of Well 5 improved from 6.4 to 7.5 igpm/ft of drawdown. However, by December, 2002, the specific capacity had declined slightly and stabilized at about 6.7 igpm/ft of drawdown. These results suggest that there was probably only a limited removal of biofilms and that this treatment was unable to remove the remaining biological material that was plugging the void spaces of the aquifer. A significant amount of biofouling material still appears to be present, restricting the permeability of the aquifer material around the well. Also, microbiological analyses conducted after treatment indicated that there is still a high level of bacterial activity in and around the well.

Well treatment results from Well 5 and other similar treatment evaluation projects indicate that when a biofouled well has experienced a decline in its original specific capacity of more than 40 percent, it becomes increasingly difficult to restore this well to its original condition (PFRA, 1999; PFRA, 2000). Although some of the biofilm and accumulates that plug the void spaces of the aquifer can be removed and additional pathways opened for water to more effectively enter the well, experience has shown that the potential for bacterial regrowth is high. The results of these studies emphasize the need to implement an ongoing monitoring program, along with preventative maintenance procedures, to reduce the risk of premature well failure.

Based on the current study results at Well 5, it is recommended that any future well treatments be designed to deal with the biofouled condition that exists around this well. Also, periodic pump tests should be conducted to monitor any changes in the specific capacity, and regular water chemistry and biological analysis should be performed. These diagnostic procedures will determine if further biological plugging is occurring around Well 5 and will indicate if additional treatments are required to prevent a decline in the specific capacity.

ACKNOWLEDGEMENTS

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

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1.0 BACKGROUND

In the spring of 1999, the Town of Qu'Appelle experienced a reduction in yield from Well 5. Subsequent diagnostic testing revealed that Well 5 was severely biofouled and had experienced an 84% decline in specific capacity since its installation in 1989. On May 21, 1999, the Prairie Farm Rehabilitation Administration (PFRA) agreed to work jointly with the Town of Qu'Appelle and Hwy One Drilling Ltd. to field test a treatment process designed specifically for biofouled wells. On June 28-30, 1999, PFRA performed the treatment on Well 5, followed by redevelopment of the well by Hwy One Drilling Ltd. Post treatment monitoring was then conducted to evaluate the efficacy of the treatment process. The results of this study are presented in a report entitled, *Town of Qu'Appelle Well Treatment Evaluation Project (PFRA; December, 1999).* The treatment process was able to improve the specific capacity of Well 5 from 2.5 to 6.5 igpm/ft, which is about 42% of its original specific capacity. Although this treatment process was effective at removing some of the plugging material, it was not able to restore the well to its original specific capacity.

1.1 Introduction

As part of PFRA's Sustainable Water Well Initiative (SWWI), ongoing laboratory studies are being conducted to investigate alternate treatment and preventative maintenance approaches for sustaining water well supplies. On March 28, 2002, a meeting was held between PFRA personnel and officials from the Town of Qu'Appelle, where PFRA proposed that an enzyme-based treatment process could be field tested on Well 5. Laboratory trials, using small-scale test cells, revealed that this treatment process showed some promise in improving the permeability of biofouled aquifer material. Consequently, in a letter dated June 6, 2002, the Town agreed to collaborate with PFRA to evaluate this treatment method. The purpose of this field study was to evaluate the effectiveness of an enzyme-based treatment process in further improving the aquifer permeability around Well 5. This treatment was applied on June 17-19, 2002, followed by post treatment monitoring until December, 2002. The study site is shown in Figure 1.

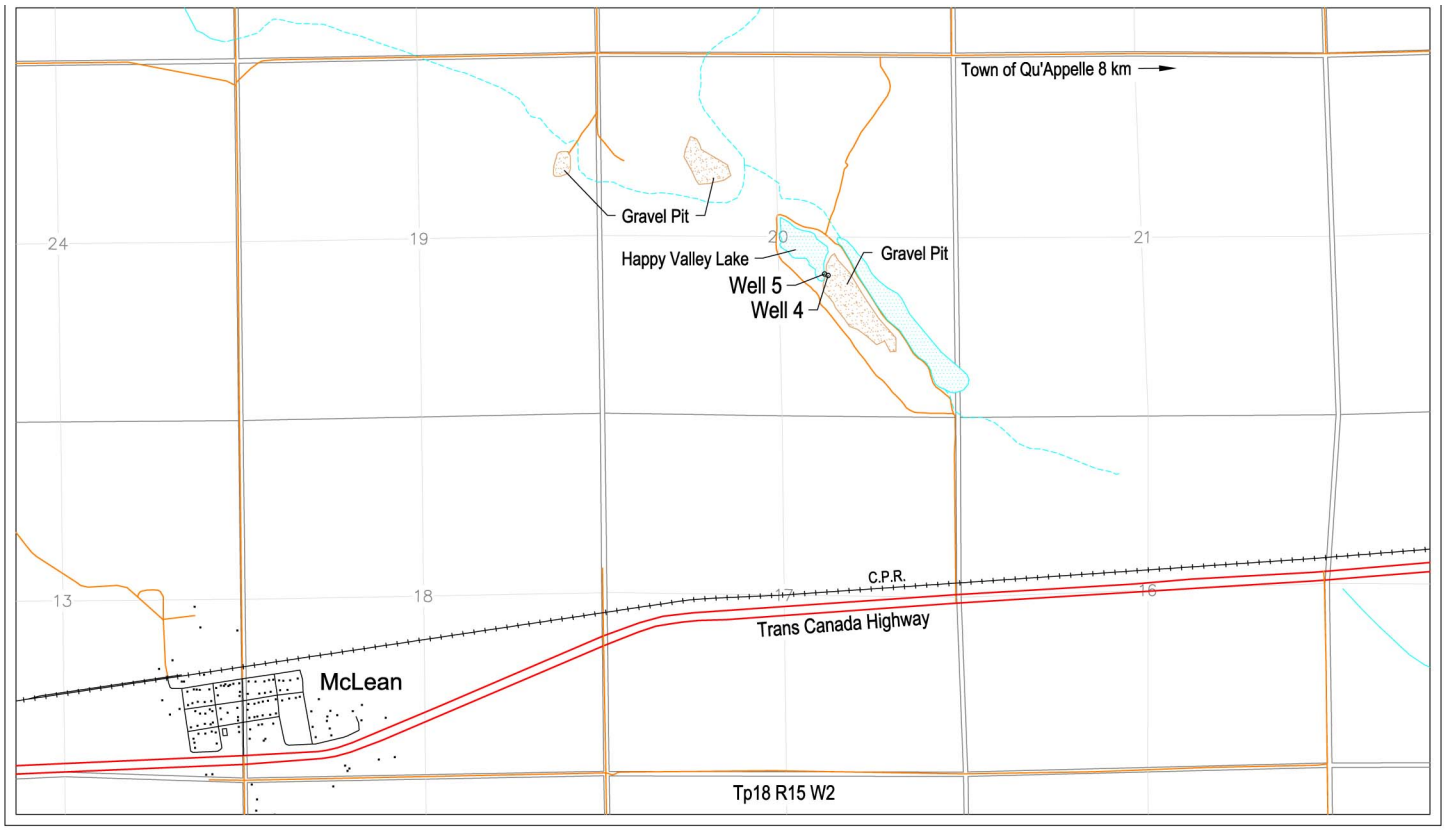

FIGURE 1. Location Plan

2.0 DIAGNOSTIC PROCEDURES AND RESULTS

The purpose of the diagnostic work is to determine the pre-treatment conditions at the well. The diagnostic procedures for this study included a down hole camera inspection of the well, a pump test, and the collection of water samples for water chemistry and microbiological analysis. These procedures are also repeated after treatment to evaluate the effectiveness of the treatment process. The results of the pre-treatment diagnostics procedures are provided in the following sections.

2.1 Down Hole Camera Inspection

On June 18, 2002, a down hole video camera inspection was conducted by PFRA personnel. The down hole camera was lowered through the entire length of the well casing and screen and revealed that the well casing was in good condition, with the biological growths increasing at a depth of about 5.5 metres below the top of casing. There were also mineral deposits and/or biological growths observed on the slots of the screen, and these deposits increased with depth.

2.2 Pump Testing

On June 14, 2002, a 60-minute pump test was conducted on Well 5 to determine its pre-treatment specific capacity and to collect water samples for microbiological analysis. During this pump test, water was pumped from the well at a constant rate of 9.24 L/s (122 igpm) and the water level was recorded at regular time intervals, as shown in Figure 2.

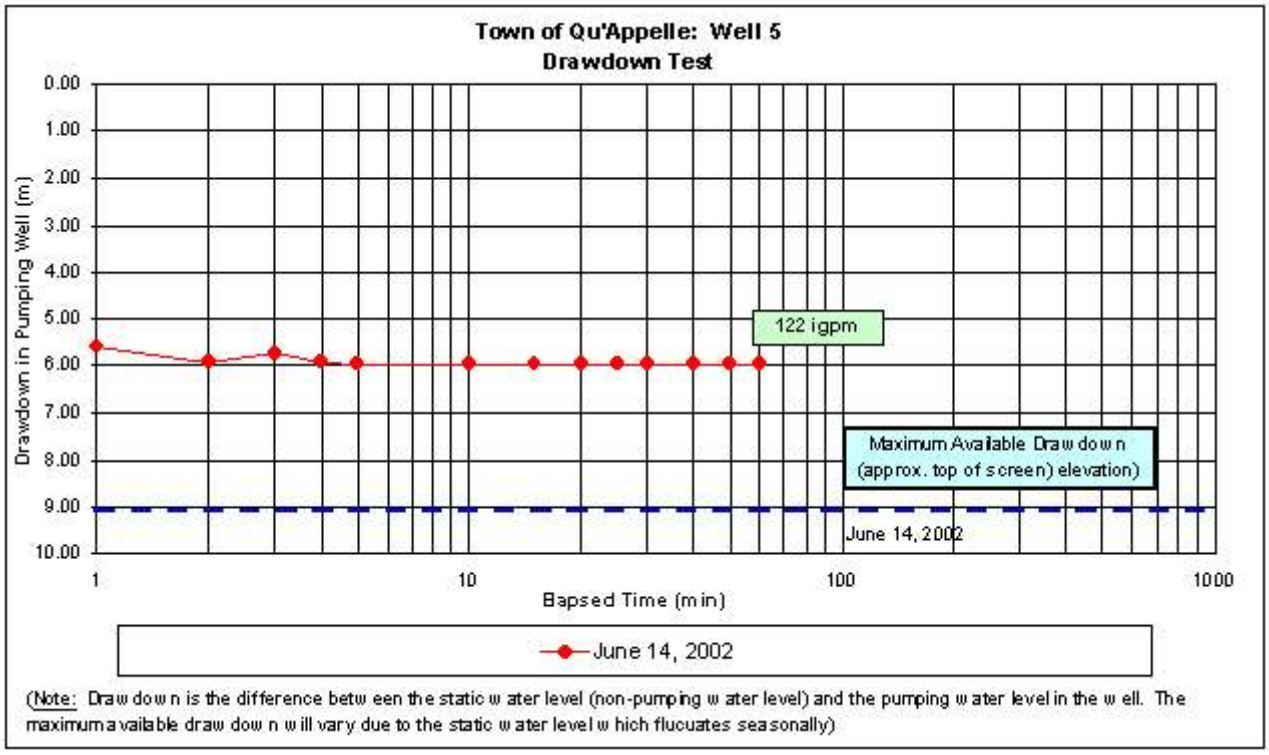

FIGURE 2 Well 5: Pre-Treatment Pump Test

The pre-treatment specific capacity of Well 5 was 6.24 igpm/ft of drawdown, which is fairly consistent with other values recorded since the previous treatment in June, 1999, is shown in Figure 3. However, the original specific capacity was reported to be 15.37 igpm/ft of drawdown, which indicates that the previous treatment was not able to remove all the biofouling material and the well would probably benefit from an additional treatment.

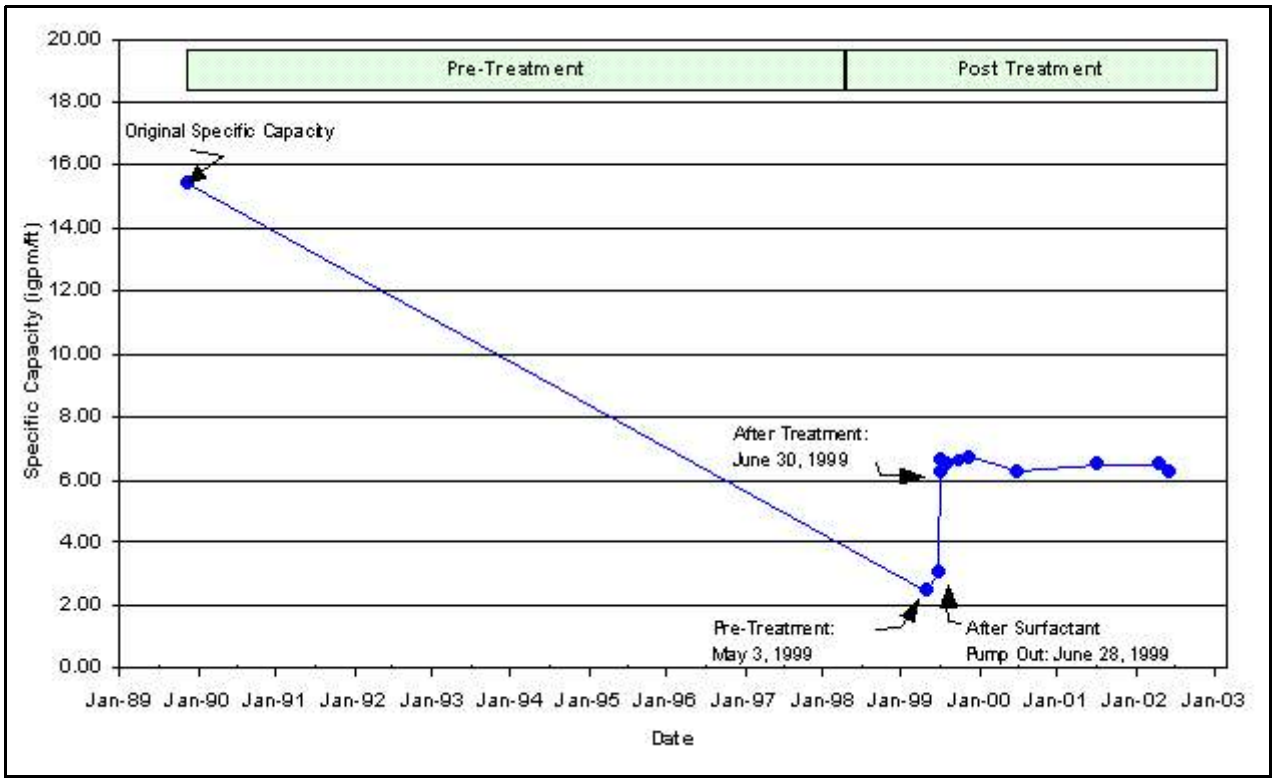

FIGURE 3 Well 5: Specific Capacity Data (Jan. 1989 to June 2002)

2.3 Water Chemistry

Water chemistry testing was not performed as part of the pre-treatment diagnostics procedures, since a water analysis had been conducted on October 31, 2001. The results of this analysis indicate that the water quality parameters are fairly stable, when compared to the previous analysis conducted on November 17, 1999 (see Table 1). The overall water is still relatively good, with a total dissolved solids of 921 mg/L.

Water Chemistry Parameter	Well 5 November 17, 1999	Well 5 October 31, 2001	Recommended Acceptable Limits
pH	7.1	8.4	6.5-9.0
Iron (mg/L)	3.3	3.5	0.3
Manganese (mg/L)	0.51	0.45	0.05
Nitrate (mg/L)	<1	0.31	45
Sulphate (mg/L)	299	247	500
Calcium (mg/L)	154	125	200
Magnesium (mg/L)	76	64	150
Chloride (mg/L)	12	11	250
Bicarbonate (mg/L)	481	445	700
Total Hardness (mg/L $CaCO_3$)	698	575	100
Total Alkalinity (mg/L $CaCO_3$)	394	365	500
Total Organic Carbon (mg/L)	6.5 *	4.8	3
Total Dissolved Solids (mg/L)	1020	921	1000-1500

* sample taken July 18, 1999

TABLE 1 Well 5: Pre-Treatment Water Chemistry

During the post treatment phase, another water analysis was conducted for comparison purposes. The results for all the water analyses for Well 5 are shown in Appendix B.

2.4 Microbiological Testing

The purpose of the microbiological testing is to determine the degree of biological activity in the well and surrounding aquifer. 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™	IRB		SRB		HAB	
Sample Time (min)	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002
10	High	High	High	High	Med	Med
30	Med	High	High	High	Med	Med
60	Med	High	High	Med	Low	Low

TABLE 2 Pre-Treatment Microbiological Aggressivity Levels

Water samples for microbiological analysis were collected at 10, 30, and 60 minutes during pump tests performed 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 both sample dates, shown in Table 3, indicate that highly aggressive populations of Iron Related Bacteria (IRB) and Sulphate Reducing Bacteria (SRB) were present. Heterotrophic Aerobic Bacteria (HAB) generally indicated medium aggressivity, but showed low aggressivity in the 60-minute sample. These results indicate that there are generally high populations of nuisance bacteria around the well. Based on the biological testing and the reduced specific capacity described in Section 2.2, Well 5 still appears to be affected by biofouling. A treatment process designed to remove biofilms that are plugging the void spaces in proximity to the well intake area is required to provide further improvements in well yield.

3.0 WELL TREATMENT

As part of the SWWI, PFRA-Technical Service has been conducting an evaluation of various well treatment chemicals and treatment processes designed to remediate biofouled wells, at the PFRA Technology Adapation Facility in Regina. 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.

3.1 Well 5 Treatment Process

In order to validate the results from ongoing PFRA laboratory studies on the effectiveness of various treatment processes, an agreement was reached between the Town of Qu'Appelle and the PFRA to field test and evaluate a new treatment process for Well 5. Based on the results of laboratory testing, an enzyme-based treatment was developed for field testing at Well 5. This treatment process consists of three distinct stages, which are described below.

The first stage of the treatment was designed to pre-heat the inside of the well screen and surrounding aquifer material. A total of 1000 litres of hot water was added to pre-heat the well to a temperature of about 50 ^{0}C.

The second stage of the treatment was designed to penetrate and break-up the biofilms and any other bio-accumulates surrounding the well intake area. During this stage, a 1253-litre solution of the enzyme Hydrolase (3% by volume) and hot water was added. The pH of this solution was about 7.2 and during the injection of this solution, the downhole temperature averaged about 42 ^{0}C. This solution remained in the well for a period of one hour and was then removed by air surging and air-lift pumping the well for about 2 hours. After this, a 3225-litre solution of hydrochloric acid (2% by volume) and hot water was added. This solution lowered the pH in the well to about 1.5 and the downhole temperature averaged about 50 ^{0}C. This acid solution then remained in the well overnight.

The third stage involved air surging and air-lift pumping for a period of about 5 hours to evacuate the biofilms from the surrounding aquifer, along with other associated plugging material. The well was then air-lift pumped until the water was clear and the pH had returned to its pre-treatment level.

3.2 Well 5 Treatment Results

The well treatment was performed on June 17-19, 2002, according to the procedures outlined in Section 3.1. On June 19, 2002, after the treatment had been completed, a downhole camera inspection was conducted which indicated that the majority of the deposits present prior to treatment had been removed. Subsequently, a pump test was conducted on June 20, 2002, which revealed that the specific capacity of Well 5 had improved from 6.4 to 7.5 igpm/ft of drawdown. Over the next seven months, pump tests were conducted to further evaluate the effects of the treatment process. During this time, the specific capacity declined slightly and stabilized at about 6.7 igpm/ft of drawdown, as shown in Figure 4. The data from these various pump tests are provided in Appendix A.

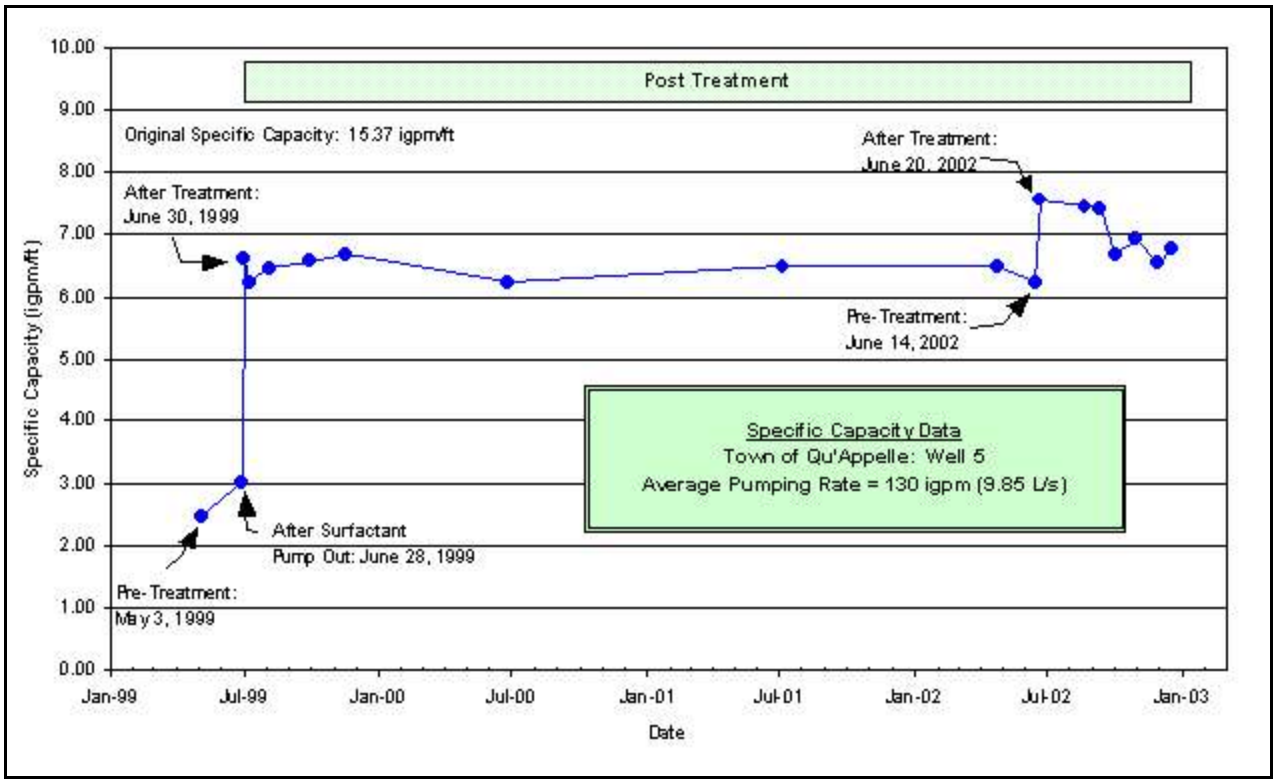

FIGURE 4 Well 5: Specific Capacity Data (May 1999 - December 2002)

During the pump test conducted on November 28, 2002, a water sample for water chemistry analysis was collected after one-hour of pumping and the results are shown in Table 3. When compared to the pre-treatment analysis completed on October 31, 2001, all of the water quality parameters have increased, except for the pH value. However, most of the parameters are still within historical variances and the water quality is fairly comparable to previous analyses, as shown in Appendix B. This deterioration in water quality may simply be a result of seasonal variations. Another possibility is that since Well 5 was not placed into operation after its treatment in June, 2002, the water withdrawn from the well during this pump test may have

Water Chemistry Parameter	Well 5 October 31, 2001	Well 5 November 28, 2002	Recommended Acceptable Limits
pH	8.4	6.8	6.5-9.0
Iron (mg/L)	3.5	6.7	0.3
Manganese (mg/L)	0.45	0.69	0.05
Nitrate (mg/L)	0.31	<1	45
Sulphate (mg/L)	247	342	500
Calcium (mg/L)	125	184	200
Magnesium (mg/L)	64	90	150
Chloride (mg/L)	11	28	250
Bicarbonate (mg/L)	445	566	700
Total Hardness (mg/L $CaCO_3$)	575	830	100
Total Alkalinity (mg/L $CaCO_3$)	365	464	500
Total Organic Carbon (mg/L)	4.8	-	3
Total Dissolved Solids (mg/L)	921	1252	1000-1500

TABLE 3 Well 5: Water Chemistry Comparisons (Oct. 2001 to Nov. 2002)

come solely from the surrounding aquifer, with little influence from the better quality water that is usually induced from nearby Happy Valley Lake. The reasons for the observed changes in the overall water quality are not well understood, and therefore, ongoing water quality monitoring is recommended to evaluate the significance of these variations.

Water samples were also collected for microbiological analysis during post treatment pump tests conducted on August 21 and November 28, 2002. The samples were collected in a similar manner to the pre-treatment samples and the results are shown in Table 4. The microbiological analyses indicated highly aggressive populations of IRB, SRB and HAB present in vicinity of the well. These results reveal that the high bacterial levels measured prior to treatment are still present. The detailed BART™ results are presented in Appendix B.

BART™	IRB			SRB			HAB		
Sample Time (min)	Pre-treatment	Post Treatment		Pre-treatment	Post Treatment		Pre-treatment	Post treatment	
	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002
10	High	High	High	High	High	High	Med	Med	Med
30	High	High	High	High	High	High	Med	Med	Med
60	High	High	High	Med	High	High	Low	Med	Med

TABLE 4 Microbiological Aggressivity Levels: June 2002 - November 2002

3.2.1 Discussion of Well Treatment Results

The enzyme-based well treatment appears to have been unable to significantly improve the specific capacity of Well 5. After treatment, the specific capacity of the well initially increased from 6.4 to 7.5 igpm/ft of drawdown, and then stabilized at about 6.7 igpm/ft of drawdown. Also, post treatment BART™ analyses indicate that the biological aggressivity levels are similar to pre-treatment levels. These findings suggest that there was probably only a limited removal of biofilms and that a significant amount of biological plugging material still appears to be blocking pathways for water to more efficiently enter the well.

Results from similar field tests of treatment processes indicate that biofouled wells that have experienced a decline of more than 40 percent from their original specific capacity are often difficult to restore to original conditions (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. Therefore, it is recommended that the Town continue to regularly conduct pump tests on Well 5, to forewarn of any further decline in specific capacity.

As part of SWWI, PFRA-Technical Service is continuing to conduct laboratory investigations to evaluate various well treatments and preventative maintenance approaches. One approach currently being field tested on Well 4, about 40 metres southeast of Well 5, is the use of an impressed current system to counteract the effects of biofouling. To date, the results appear promising and in the future, this, or other methods could be field tested at Well 5 to evaluate their effectiveness in removing the biological plugging material from the aquifer and improving the specific capacity of the well.

Ongoing water chemistry and biological analysis should also be conducted to observe any changes in water quality, along with periodic pump tests to monitor the well performance. These diagnostic procedures should forewarn of any further biological plugging, and provide guidance on whether further well treatments or preventative maintenance procedures are required.

4.0 CONCLUSIONS

1. Well 5 experienced only a marginal increase in specific capacity, from 6.4 to 6.7 igpm/ft of drawdown, as a result of the well treatment applied on June 17-19, 2002.

2. Based on the BART™ results, highly aggressive levels of biological activity still exist around Well 5. Although the specific capacity of Well 5 improved after treatment, results suggest that there was probably only a limited removal of biofilms and that the well treatment was unable to remove any of the remaining biological material that was plugging the void spaces of the aquifer.

3. The overall water quality is considered satisfactory, with reported total dissolved solids ranging from 809 mg/L to 1252 mg/L, since the installation of Well 5 in November 1989.

5.0 RECOMMENDATIONS

1. It is recommended that any future well treatments for Well 5 continue to be designed to deal with the biofouled condition around this well.

2. Based on the post treatment pump test results shown in Appendix A, Well 5 has a pumping capacity of at least 135 igpm. However, it is recommended that Well 5 be pumped at a reduced pumping rate of about 100 igpm, which should reduce its plugging potential.

3. In order to forewarn of further biological plugging, it is recommended that ongoing monitoring of Well 5 be continued, which includes regular pump testing and water chemistry and microbiological testing.

6.0 REFERENCES

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

PFRA, 2000. *City of North Battleford Well Rehabilitation Project - Summary Report*. September 2000. Prairie Farm Rehabilitation Administration, Technical Service - Earth Sciences Unit.

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

APPENDIX A:

Well Log and Well Construction Details
Pump Test Data

APPENDIX B:

Water Chemistry Data
Biological Activity Reaction Test (BART™) Data

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. 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.

Iron Related Bacteria	IRB-BART™	Red Cap
Sulfate Reducing Bacteria	SRB-BART™	Black Cap
Heterotrophic Aerobic Bacteria	HAB-BART™	Blue Cap

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

Prior to treatment, pump test were conducted and water samples were collected for BART™ analysis . These samples were collected on April 24th and June 14th, 2002, 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)	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002
10	4	3	5	3	4	3
30	5	3	5	4	4	4
60	5	3	6	7	7	6

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

BART™	IRB		SRB		HAB	
Sample Time (min)	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002	April 24, 2002	June 14, 2002
10	High	High	High	High	Med	Med
30	Med	High	High	High	Med	Med
60	Med	High	High	Med	Low	Low

Table 3: Levels of Microbiological Aggressivity

Pre-Treatment BART™ Data Interpretation:

BART™ tests performed on each of these water samples confirmed the presence of high to medium aggressive populations of Sulphate Reducing Bacteria (SRB) and Iron Related Bacteria (IRB). Heterotrophic Aerobic Bacteria (HAB) were generally reported to show medium to low aggressivity. These results indicate that biofouling is still occurring in Well 5 and in the surrounding aquifer material.

Post Treatment BART™ Test Results: Well 5

On August 21 , 2002, approximately two months 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. A similar test was also conducted on November 28, 2002. 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)	Pre-treatment	Post Treatment		Pre-treatment	Post Treatment		Pre-treatment	Post treatment	
	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002
10	3	3	3	3	3	3	3	4	4
30	3	3	3	4	3	4	4	3	4
60	3	3	4	7	3	3	6	3	4

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

BART™	IRB			SRB			HAB		
Sample Time (min)	Pre-treatment	Post Treatment		Pre-treatment	Post Treatment		Pre-treatment	Post treatment	
	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002	June 14, 2002	Aug. 21, 2002	Nov. 28, 2002
10	High	High	High	High	High	High	Med	Med	Med
30	High	High	High	High	High	High	Med	Med	Med
60	High	High	High	Med	High	High	Low	Med	Med

Table 5: Levels of Microbiological Aggressivity

Post Treatment 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), and medium aggressivity levels of Heterotrophic Aerobic Bacteria (HAB). The HAB, IRB and SRB populations appear to have either remained the same or increased, suggesting 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.