EXECUTIVE SUMMARY

From April 1998 to December 1999, the City of North Battleford Well Rehabilitation Project was completed as a joint-venture partnership between PFRA-Technical Service, Droycon Bioconcepts Incorporated (DBI) and the City of North Battleford, with some funding provided by the Canada-Saskatchewan Agri-Food Innovation Fund (AFIF). The purpose of this project was to evaluate the extent and nature of biofouling in the City of North Battleford well field, and to field test appropriate well treatment procedures. The City of North Battleford Well Rehabilitation Project was divided into three phases: a diagnostics phase, a well treatment evaluation phase and a post treatment monitoring phase. The findings from this project are provided in the following reports: *City of North Battleford Well Rehabilitation Project, Phase 1: Well Diagnostics Program (PFRA and DBI, June 1999)*, *City of North Battleford Well Rehabilitation Project, Phase 2: Well Treatment Evaluation (PFRA and DBI, December 1999), and City of North Battleford Well Rehabilitation Project, Phase 3: Post Treatment Monitoring (PFRA and DBI, April 2000)*.

Upon completion of the City of North Battleford Well Rehabilitation Project, a follow-up project was initiated to evaluate the latest modification to the Ultra-Acid Base™ (UAB™) treatment process. In July, 2000, a partnership agreement was prepared and signed by the City of North Battleford, Droycon Bioconcepts Inc. (DBI) and PFRA-Technical Service to jointly undertake this project, with field tests of the treatment process performed on Wells 16 and 17 during August, 2000. In October, 2000, about two months after treatment, pump tests were conducted to measure the specific capacity of the wells and to collect water samples for microbiological analysis. Based on these post treatment results, the UAB™ treatment conducted on Wells 16 and 17 is considered to be only moderately successful. After treatment, Well 16 had a specific capacity of 14.3 igpm/ft, about 30% below original, while Well 17 had a specific capacity of 18.9 igpm/ft, about 5% below original.

Microbiological testing indicates that the well treatments did not have a noticeable effect on the aggressivity levels of the nuisance bacteria around the wells, since a significant change in biological aggressivity was not observed after treatment. It appears that the regrowth of the nuisance bacteria around Well 16 occurs quickly, and even with annual well treatments, the projected specific capacity trend line indicates that the specific capacity may decline to about 10 igpm/ft within 2 years. The regrowth of the nuisance bacteria around Well 17 also occurs fairly quickly. However, the biofilms appear to breakdown more easily at this site, and therefore, with annual treatments, the projected life of this well should be at least another 10 years.

Although the UAB™ treatment process, which has been field tested on the City of North Battleford wells over the past three years, was found to be more effective than previous treatments, the treatment process is not able to completely breakdown and remove all the biological plugging material. Further research is still required to develop techniques for applying well treatments that more effectively breakdown and remove biofilms around the well, in order that the usable life of the well can be extended. As well, ongoing monitoring should continue in order to evaluate the long-term effectiveness of the well treatments and to signal when appropriate preventative maintenance (PM) procedures or well treatments are required. This includes conducting pump tests and collecting water samples for microbiological analysis. It is recommended that preventative maintenance be applied before the specific capacity has declined more than 20% from original or when the biological activity has increased by one order of magnitude, and well treatments should be conducted before the specific capacity has declined more than 40% or the biological activity has increased by two orders of magnitude.

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Project Partners:

Droycon Bioconcepts Incorporated (DBI):
We gratefully acknowledge Dr. Roy Cullimore for his technical input and guidance during the course of this project, and Brent Keevill for his expertise in the microbiological assessment of the wells, and for his close collaboration with PFRA staff during the field work and in the laboratory studies.

City of North Battleford:
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Elk Point Drilling Corporation:
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Project Funding:

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1.0 BACKGROUND

During April 1998 to December 1999, the City of North Battleford Well Rehabilitation Project was completed through a partnership arrangement between PFRA-Technical Service, Droycon Bioconcepts Incorporated (DBI) and the City of North Battleford, with some funding provided by the Canada-Saskatchewan Agri-Food Innovation Fund (AFIF). A project review was held on June 14, 2000, at the City of North Battleford between Randy Strelioff and Ivan Katzell of City of North Battleford, Harry Rohde of PFRA and Brent Keevill of DBI. At this meeting, the City indicated that there had been a reduction in specific capacity at both Wells 16 and 17, and they expressed an interest in conducting further field tests of the UAB™ treatment process at these sites. DBI and PFRA had been conducting laboratory studies on an alternate acid for the UAB™ process, and were prepared to field test this latest modification to the treatment process. The City of North Battleford requested that PFRA and DBI enter into another partnership agreement with the City, to conduct a further evaluation of the UAB™ treatment process at Wells 16 and 17. The City of North Battleford well field is shown in Figure 1.

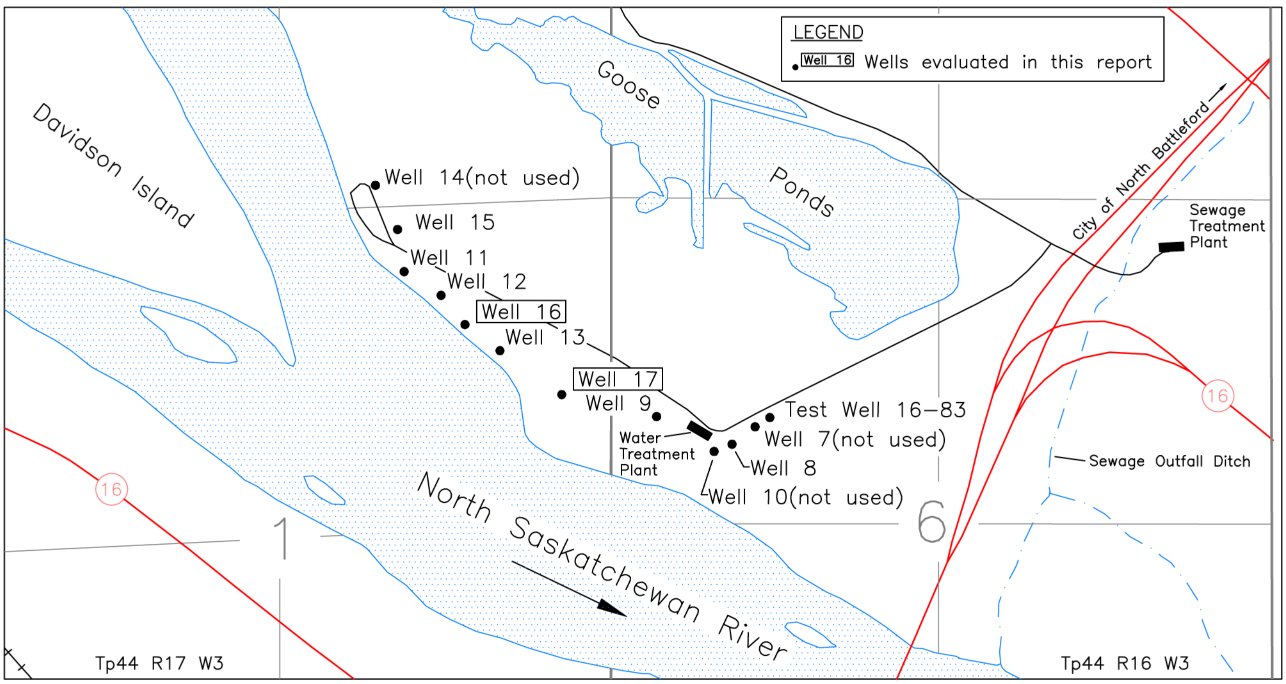

FIGURE 1 City of North Battleford Well Field

1.1 Introduction

The purpose of this well treatment evaluation project is to field test and evaluate the latest modification to the UAB™ treatment process. In July, 2000, a partnership agreement was prepared and signed by the City of North Battleford, DBI and PFRA-Technical Service to initiate this project. The field testing of the treatment process at Wells 16 and 17 commenced on August 14, 2000, and was completed on August 17, 2000. After treatment, pump tests were conducted to measure the specific capacity of the wells, for comparison to measurements collected prior to treatment. On October 3-4, 2000, pump tests were conducted again to collect water samples for microbiological analysis. The results of this well treatment evaluation are provided in this report.

2.0 MATERIAL AND METHODS

2.1 Pump Testing Procedures

On July 10-11, 2000, the City of North Battleford conducted pump tests on Wells 16 and 17 to measure their specific capacities prior to the hydrochloric acid treatments applied by the City on July 19, 2000, and the subsequent redevelopment work conducted by Elk Point Drilling. Pump tests were also conducted after these acid treatments and again after the UAB™ treatments applied on August 14-17, 2000, in order to evaluate the effectiveness of these well rehabilitation efforts. During each test, the well is pumped at a constant rate and the water level in the well is recorded at regular time intervals. The detailed pump test results are provided in Appendix A.

2.2 Microbiological Testing Procedures

During a 2-hour pump test on each well, water samples are collected for microbiological analysis, at 3, 10, 30, 60 and 120 minutes. The biological activity is then evaluated by using the Biological Activity Reaction Test (BART™), which determines the presence and aggressivity of the bacteria that cause biofouling problems. The BARTs™ used for the microbiological testing of the water samples are the HAB-BART™ (heterotrophic bacteria), the IRB-BART™ (iron related bacteria), the SRB-BART™ (sulphate reducing bacteria), the SLYM-BART™ (slime forming bacteria) and the DN-BART™ (denitrifying bacteria). The water samples are placed into the BART™ biodetectors on the sample collection date and are then examined once a day for ten consecutive days, with any observed reactions recorded. Water samples were collected for microbiological analysis prior to the UAB™ treatment, on August 1-2, 2000, and after treatment, on October 3-4, 2000.

2.3 UAB™ Treatment Process

The Ultra-Acid Base (UAB™) treatment process applied during this project had been slightly modified to reflect the results of recent laboratory experimentation conducted jointly by PFRA and DBI. On August 14-17, 2000, this modified treatment process was field tested and evaluated by DBI and PFRA at Wells 16 and 17. This treatment process consists of three distinct phases.

The ***first phase*** involves preheating the area around the well screen. This step initiates the removal of biological slimes that have restricted or plugged the void spaces in the sand pack and aquifer material around the well screen. A 1250-litre hot water and 100-litre acid solution, with CB-4 wetting agent (1% by volume), is heated to about 85°C and injected into each well. The acid solution consists of glycolic acid* (5% by volume) combined with sulfamic acid (10g/L). After the acid solution has been added, the well screen interval is air-developed and surged in one-metre increments from the bottom to the top of the screen. At each one-metre increment a minimum of 15 minutes of air-surging was conducted. This development procedure moves the chemical solution into the surrounding sand pack and aquifer material, and allows the treatment chemicals to penetrate more restrictive areas of the aquifer. The surging action also helps to dislodge biological plugging material and move it into the well where it can be removed by pumping. This development period is about two hours in duration, during which time no water is discharged from the well. After this, the acid solution remains in the well overnight. The next day, air-lift pumping is conducted in one-metre increments from the top to the bottom of the screen to remove the material dislodged during this initial phase of the well treatment.

*also known as hydroxyacetic acid

The ***second phase*** is designed to further disrupt and dislodge the plugged or biofouled areas from the sand pack and surrounding aquifer. This is achieved by inducing a pH "flip-flop", by altering the pH from about 9.0 to 2.0, in and around the well screen. Applying a pH shift of seven units over a very short time period can cause severe disruption of the biofilms and is lethal to most bacteria. This pH shift was obtained by first injecting a solution which consists of 2500 litres of hot water and 25 litres of sodium hypochlorite into each well to obtain a pH of about 9.0. After this step, a 2500-litre hot water and 400-litre hydrochloric acid solution is injected into each well to obtain a pH of about 2.0. Both steps include the use of the CB-4 wetting agent(1% by volume). Development and air-lift pumping procedures conducted after each step are similar to those performed during the first phase of treatment.

The ***third phase*** is designed to facilitate the dispersion and removal of the biofilms from the aquifer, along with other associated plugging material. Removal is achieved by surging (air or mechanical), and air-lift pumping. The main purpose of the surging (redevelopment) is to suspend the disrupted plugging material so it can be removed by air-lift pumping. Redevelopment and air-lift pumping continues until the water is clear and the pH has returned to its original level. When the redevelopment has been completed the pump can be reinstalled into the well. Once the pump is in place, alternating the pumping rate can also assist in causing additional detachment of plugging material and improved well rehabilitation.

3.0 PROJECT RESULTS

3.1 Specific Capacity Measurements

On November 29, 1999, at the conclusion of the post treatment monitoring phase of the previous well rehabilitation project completed for the City of North Battleford, the specific capacity of Wells 16 and 17 were measured at 18.1 and 24.2 igpm/ft, respectively (PFRA and DBI, 2000). Prior to the hydrochloric acid treatments applied on July 19, 2000, the specific capacity of Wells 16 and 17 had each declined about 40 percent. After the acid treatments and subsequent UAB™ treatments on August 14-17, 2000, the specific capacity of Wells 16 and 17 were again measured to evaluate the effectiveness of these treatments. The specific capacity measurements calculated for each well at the various stages are provided in Table 1, with the detailed pump test results included in Appendix A.

Date (2000)	Well 16 Original Specific Capacity: 20 igpm/ft (1995)			Well 17 Original Specific Capacity: 20 igpm/ft (1995)		
	Specific Capacity (igpm/ft)	Per Cent of Original Specific Capacity	Comments	Specific Capacity (igpm/ft)	Per Cent of Original Specific Capacity	Comments
July 10-11	11.24	56.2	pre acid treatment	14.64	73.2	pre acid treatment
August 1-2	14.01	70.1	post acid treatment pre UAB™ treatment	16.75	83.8	post acid treatment pre UAB™ treatment
August 15-17	15.69	78.5	post UAB™ treatment	18.73	93.7	post UAB™ treatment
October 4-5	14.30	71.5	ongoing monitoring	18.89	94.5	ongoing monitoring

NOTE: Specific capacity measurements are presented as imperial gallons per minute per foot of drawdown (igpm/ft).

TABLE 1 Specific Capacity Measurements

3.1.1 Well 16

Well 16 had received an initial UAB™ treatment in August, 1998, and a second UAB™ treatment in July, 1999. After these well treatments, the specific capacity of Well 16 improved to about 19 igpm/ft, which is about 95 percent of the original specific capacity, as shown in Figure 2. However, by July 10, 2000, the specific capacity had declined to about 11 igpm/ft, and therefore, another well treatment was necessary. On July 19, 2000, the City of North Battleford proceeded to perform a hydrochloric acid treatment on Well 16 and the specific capacity improved to about 14 igpm/ft. In an attempt to further improve the specific capacity and eliminate additional biological plugging material, a UAB™ treatment was conducted on August 14-15, 2000. Immediately after treatment, the specific capacity improved to 15.7 igpm/ft. However, subsequent testing on October 4, 2000, revealed that the specific capacity had declined to about 14 igpm/ft. Past experience has shown that biological regrowth occurs fairly quickly, and therefore, ongoing monitoring is recommended and preventative maintenance procedures will have to be applied again shortly to maintain the specific capacity above 14 igpm/ft.

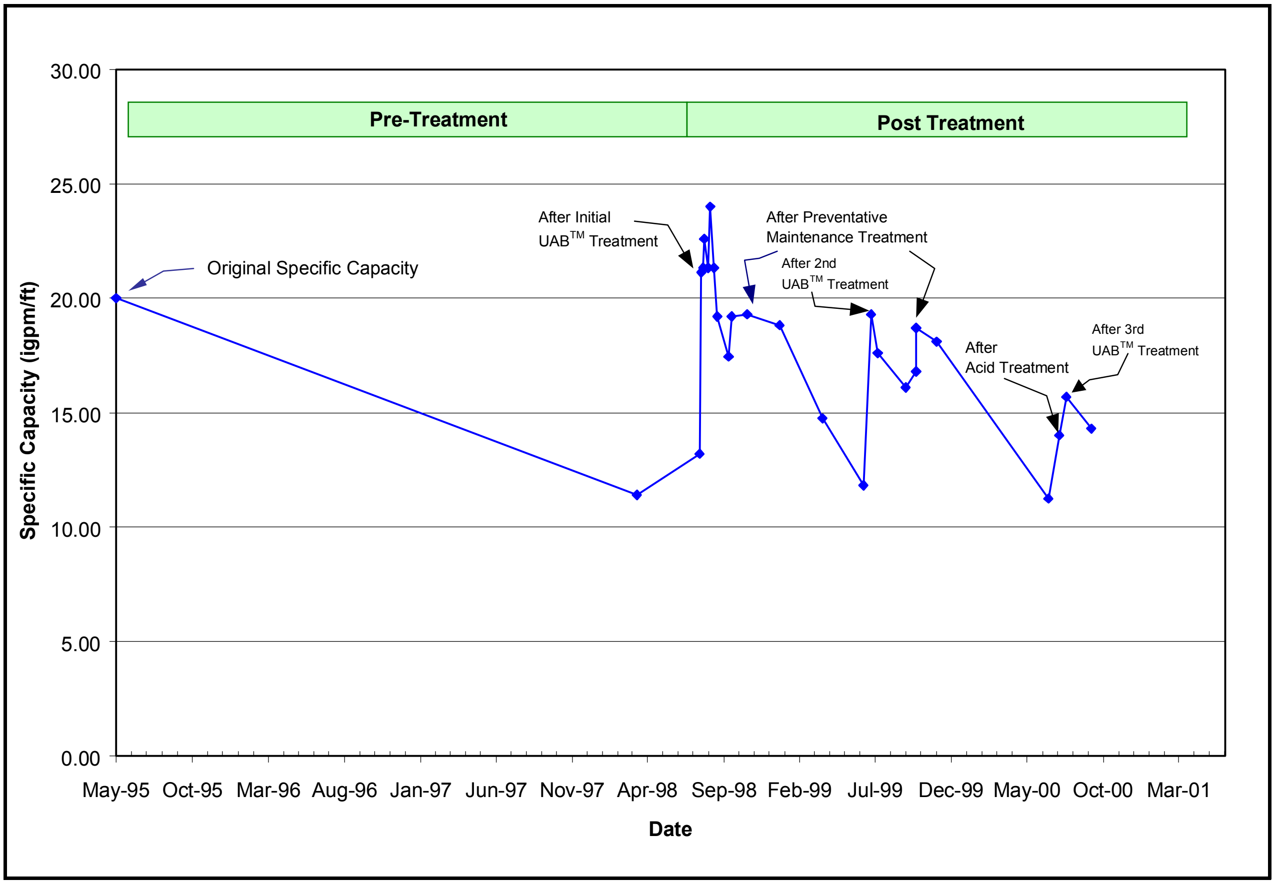

FIGURE 2 Well 16: Specific Capacity Measurements 1995-2000

3.1.2 Well 17

Well 17 received an initial UAB™ well treatment in July, 1999. After this treatment, the specific capacity of Well 17 recovered close to its original specific capacity, and continued to improve over the subsequent months, as shown in Figure 3. However, a pump test performed on July 11, 2000, indicated that the specific capacity had declined to 14.6 igpm/ft, and therefore, the City of North Battleford performed an acid treatment on Well 17, and the specific capacity improved to about 17 igpm/ft. In an attempt to further improve the specific capacity, a UAB™ treatment was applied on August 15-16, 2000. Pump tests conducted immediately after treatment, and again on October 4, 2000, indicate that the specific capacity has improved to about 19 igpm/ft. However, past experience has shown that biological regrowth occurs fairly quickly, and therefore, ongoing monitoring is recommended and preventative maintenance procedures may have to be applied within a year if the specific capacity begins to decline.

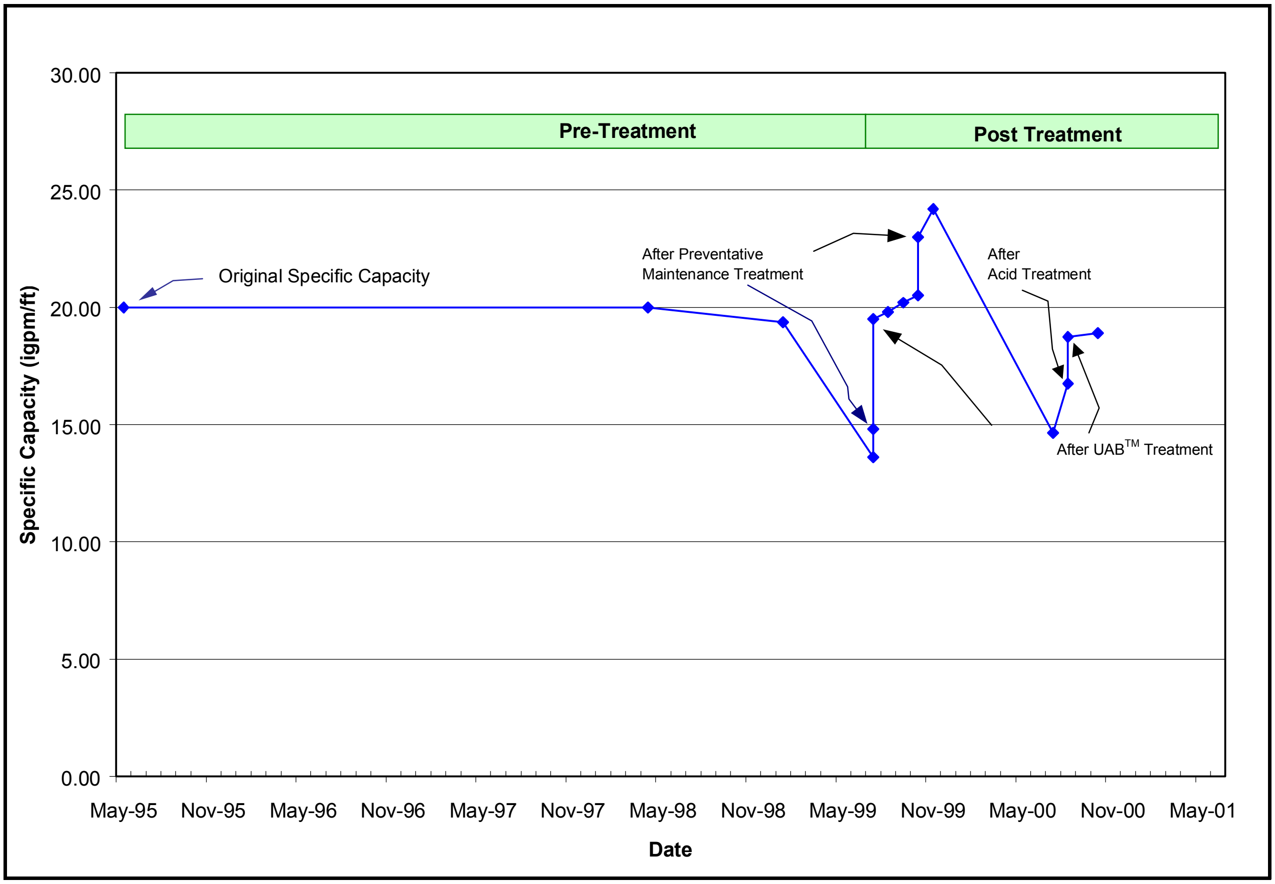

FIGURE 3 Well 17: Specific Capacity Measurements 1995-2000

3.2 Microbiological Testing

The microbiological testing involved collecting water samples at 3, 10, 30, 60 and 120 minutes during 2-hour pump tests conducted on Wells 16 and 17. The BART™ biodetectors were used to determine the presence and aggressivity of the bacteria around each well. The results obtained for each well are described below and the detailed test data is provided in Appendix B.

3.2.1 Well 16

After the acid treatment conducted in July, 2000, results from the BART™ analyses indicated that highly aggressive levels of biological activity were still present around the well (see Appendix B). BART™ analyses were also conducted on water samples collected on October 4, 2000, about two months after the UAB™ treatment. The results from these analyses indicate that the overall aggressivity of the HAB was reduced by one order of magnitude and the SRB analysis from the 60 and 120-minute samples show reduced aggressivity levels. Otherwise, the biological activity measured around the well is still similar to the pre-treatment results, as shown in Table 2. However, further biological testing should be conducted to determine the long-term effectiveness of the UAB™ treatment at reducing the biological aggressivity of the HAB and SRB in vicinity of the well.

BART™	Well 16		Well 17	
	August 1, 2000 (after acid treatment)	October 4, 2000 (after UAB™ treatment)	August 2, 2000 (after acid treatment)	October 3, 2000 (after UAB™ treatment)
HAB	high	medium	medium	medium
IRB	medium	high	high	high
SRB	low	low	high	medium
SLYM	high	high	high	high
DN	medium	medium	low	medium

TABLE 2 BART™ Results (after 120 minutes of pumping)

3.2.2 Well 17

After the acid treatment conducted in July, 2000, results from the BART™ analyses indicate that the IRB, SRB and SLYM bacteria have high aggressivity levels and the HAB and DN bacteria have a medium to low aggressivity levels, as shown in Table 2. BART™ analyses were also conducted on water samples collected on October 3, 2000, about two months after the UAB™ treatment. A comparison of this data to the pre-treatment analyses conducted on August 2, 2000, suggests that the microbiological activity has not changed significantly, and that the well treatments and preventative maintenance procedures have had limited success in reducing the aggressivity levels of the nuisance bacteria around Well 17. The only exception to this are the sulphate reducing bacteria, which showed a three- order of magnitude decrease in aggressivity levels for the 120-minute sample (see Appendix B). This suggests that the treatment was effective at reducing the aggressivity levels of anaerobic bacteria in areas further away from the well. Regular testing is recommended to monitor any changes in biological aggressivity levels around the well.

4.0 DISCUSSION OF FINDINGS

The purpose of this study was to further field test and evaluate the UAB™ treatment process. The treatment process has been slightly modified from the treatments conducted on Wells 16 and 17 in the summer of 1999, with glycolic acid replacing acetic acid in the first phase of treatment, as described in section 2.3 of this report. Glycolic acid was selected for testing, since it is effective in traumatizing biofilms and its fumes are less hazardous than those of acetic acid. However, like acetic acid, glycolic acid is still poor at removing carbonate and sulphate scale, and therefore, sulfamic acid is added to remove any of these mineral scales. The addition of sulfamic acid also assists in maintaining the pH at the required level in the well during the UAB™ treatment process.

The UAB™ well treatments applied in August, 2000, were only moderately successful in recovering lost specific capacity in Wells 16 and 17. Specific capacity data collected for these wells over the last two years suggests that the treatment process is unable to completely remove the biological plugging material around these wells. After a well treatment, biological regrowth appears to occur fairly rapidly, generally within a few months to a year, reducing the specific capacity and ultimately resulting in additional well treatments. Therefore, the biomass that has accumulated around these wells appears to be well-established and is very difficult to breakdown and remove.

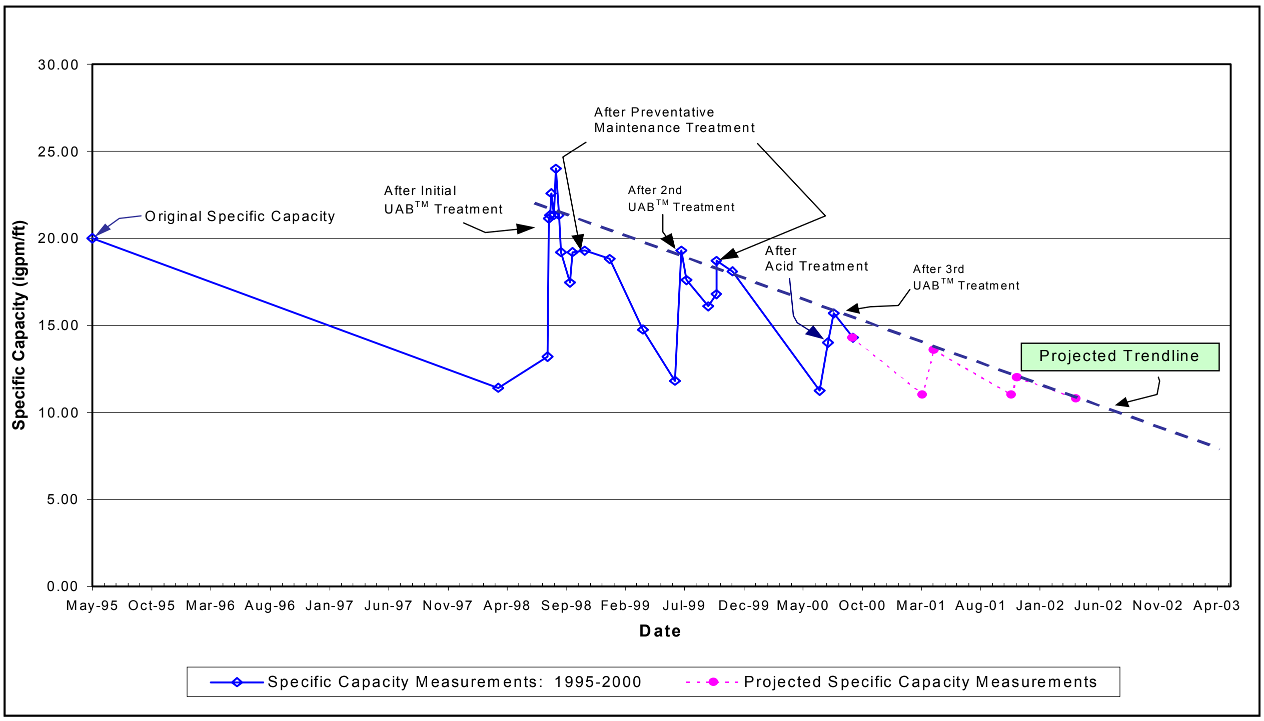

FIGURE 4 Well 16: Projected Specific Capacity Measurements

After the UAB™ treatment applied in August, 2000, the specific capacity at Well 16 recovered to 15.7 igpm/ft, which is about 80 per cent of its original specific capacity. Previous UAB™ treatments, in 1998 and 1999, were able to improve the specific capacity to at least 95 per cent of original, which suggests that the treatments are becoming less effective in removing the remaining biomass around the well (see Figure 4). Similar to previous treatment results, the recovery in specific capacity was also short-lived. By October, 2000, the specific capacity fell to 14.3 igpm/ft, which is about 70 per cent of original. Since well treatments are recommended before the specific capacity has declined more than 40 per cent of original (PFRA and DBI, April 2000), ongoing monitoring is required to determine the effectiveness of the treatment and to target further well treatments. Previous research by DBI suggests that once a well has had a reduction in specific capacity of greater than 40 per cent due to biological plugging, it becomes extremely difficult to restore the specific capacity to original levels (Keevill, 2000). Well 16 was initially treated after its specific capacity had dropped to about 43 per cent (PFRA and DBI, December 1999), which may account for the difficulty this well is experiencing in maintaining its specific capacity. A projection of the specific capacity measurements taken after treatment indicate that, even with annual well treatments, within 2 years the specific capacity of Well 16 may fall below 10 igpm/ft (see Figure 4). Therefore, unless a method is found to apply well treatments in a manner that is more effective at breaking down and removing the biofilms, well replacement may have to be considered by 2002.

After the UAB™ treatment applied in August, 2000, the specific capacity at Well 17 recovered to 18.7 igpm/ft, which is only slightly less than the previous treatment result in July, 1999. However, previously, the specific capacity continued to improve in the months following the treatment, while this time, two months after treatment, the specific capacity has remained fairly constant. Unlike Well 16, the specific capacity at Well 17 has not declined, and the well treatments appear to be more effective at removing the biological plugging material. However, the biological regrowth still occurs fairly quickly, and annual well treatments appear necessary to maintain the efficiency of this well. Since both Wells 16 and 17 were installed at the same time and have been operated in a similar manner, the only obvious difference is that Well 17 is located further from the river, and therefore, further from a nutrient source which encourages biological growth around these wells.

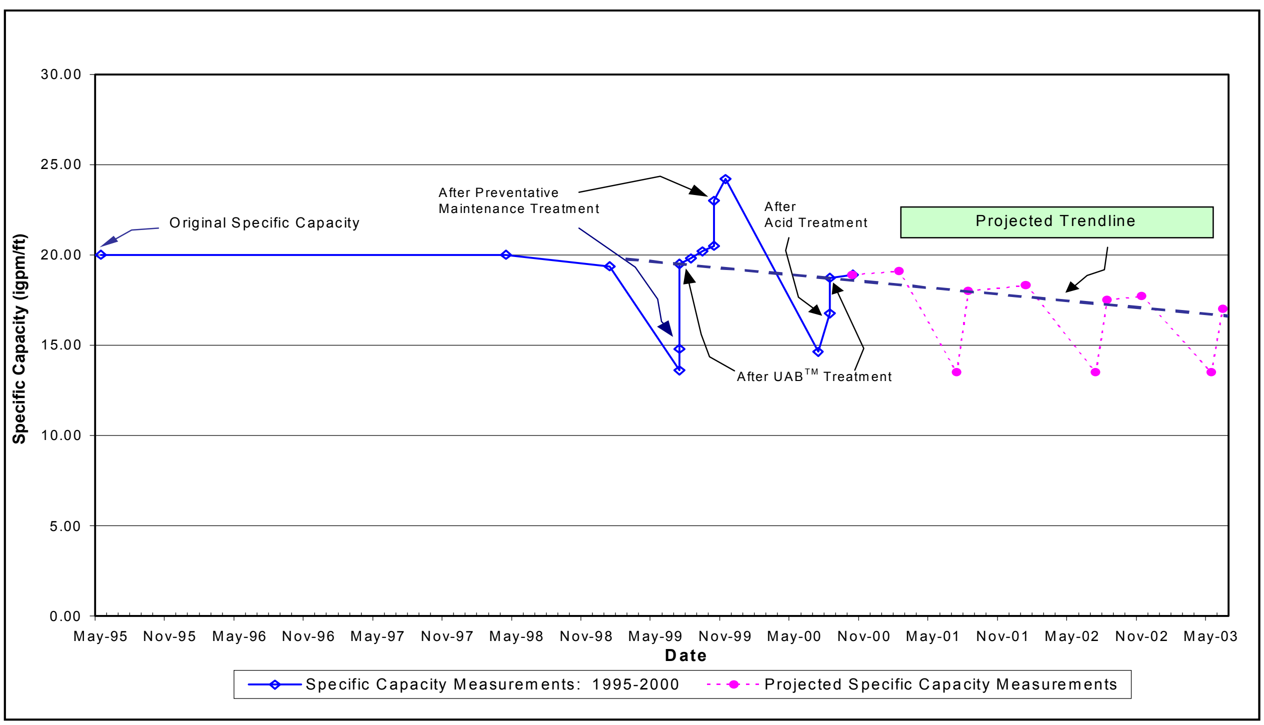

FIGURE 5 Well 17: Projected Specific Capacity Measurements

The projected trend line for specific capacity measurements from Well 17 suggest that with annual well treatments the decline in specific capacity is less severe than for Well 16, and the usable life of the well should be at least another 10 years (see Figure 5). Ongoing monitoring is recommended to determine the long-term effectiveness of the well treatment and to target further well treatments.

The working partnership between PFRA, DBI and the City of North Battleford over the past three years has resulted in laboratory research and field testing to evaluate and refine the UAB™ treatment process. Although the UAB™ treatment process was found to be more effective than previous treatments conducted on the City of North Battleford wells, the treatment process is not able to completely breakdown and remove the biological plugging material. There may be several reasons for this, not withstanding, the proximity of these wells to the river, which provides a continual source of nutrients that support and encourage biological growth. Since there appears to be incomplete removal of the biological plugging material from around these wells, further research is recommended to determine the particle-size reduction achieved during the treatment process, and more importantly, the size of the particles left behind that could not be mobilized. The results of this research would hopefully provide a better understanding of the particle size reduction required to mobilize the biofilm through the pore spaces of the aquifer material. As well, research is also recommended to determine the required residency times for the chemicals in the aquifer to effectively reduce the biofilms to particle sizes that can be mobilized and removed from the aquifer by pumping.

5.0 CONCLUSIONS

1. The regular pump testing and microbiological testing has proven to be useful in indicating when well treatments or preventative maintenance procedures are required.

2. The UAB^{TM} well treatments conducted on Wells 16 and 17 in August, 2000 have only been moderately successful. In October, 2000, two months after treatment, Well 16 reported a specific capacity of about 30% below original, while Well 17 reported specific capacity of about 5% below original.

3. The regrowth of the nuisance bacteria around Well 16 occurs quickly, and even with annual well treatments, the projected specific capacity trend line indicates that the specific capacity may decline to about 10 igpm/ft within 2 years.

4. The regrowth of the nuisance bacteria around Well 17 also occurs fairly quickly. However, the biofilms appear to breakdown more easily at this site. Therefore, with annual treatments, the projected usable life of this well should be at least another 10 years.

5. The microbiological testing conducted with the BART^{TM}s indicates that the well treatments do not appear to have much effect on aggressivity levels of the nuisance bacteria present around the wells, since there is not much of a change in biological aggressivity after treatment.

6. Although the UAB^{TM} treatment process was found to be more effective than previous treatments conducted on the City of North Battleford wells, the treatment process is not able to completely breakdown and remove the biological plugging material.

7. Further research is required to determine the manner in which well treatments need to be applied to more effectively breakdown and remove biofilms around the well, in order that the usable life of the well can be extended.

6.0 RECOMMENDATIONS

1. It is recommended that regular monitoring of the wells be continued, which includes pump testing and collecting water samples for microbiological analysis. These tests should be conducted at least every three months, with the frequency adjusted to reflect the observed condition in each well.

2. It is recommended that preventative maintenance be applied before the specific capacity has declined more than 20% from original, or when the biological activity has increased by one order of magnitude, and well treatments be conducted before the specific capacity has declined more than 40% or the biological activity has increased by two orders of magnitude.

3. Further research is recommended to determine the manner in which well treatments need to be applied to more effectively breakdown and remove the biofilms around the well. This includes determining the residency times for the treatment chemicals in the aquifer so they are able to reduce the biofilms to particle sizes that can be effectively mobilized and removed.

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APPENDIX A:

Pump Test Data

Pump Test of North Battleford Well 16: July 10, 2000 and August 1, 2000

Pump rate: 123 Igpm
Specific Capacity: 11.24 Igpm/ft (@110 min.)

July 10, 2000

Static Water Level (m bTOC):			3.96
Stickup (m ags):			
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	12.98	3.956	0.000
1	23.05	7.026	3.069
2	23.60	7.193	3.237
3	23.74	7.236	3.280
4	23.78	7.248	3.292
5	23.79	7.251	3.295
10	23.80	7.254	3.298
15	23.81	7.257	3.301
20	23.81	7.257	3.301
25	23.81	7.257	3.301
30	23.82	7.260	3.304
40	23.83	7.263	3.307
50	23.85	7.269	3.313
60	23.87	7.276	3.319
70	23.89	7.282	3.325
80	23.91	7.288	3.331
90	23.91	7.288	3.331
100	23.92	7.291	3.335
110	23.92	7.291	3.335

Pump rate: 180 Igpm
Specific Capacity: 14.01 Igpm/ft (@120 min.)

August 1, 2000

Static Water Level (m bTOC):			3.55
Stickup (m ags):			
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	11.65	3.551	0.000
2	23.80	7.254	3.703
3	23.90	7.285	3.734
4	23.98	7.309	3.758
5	24.00	7.315	3.764
10	24.10	7.346	3.795
15	23.97	7.306	3.755
20	23.97	7.306	3.755
25	24.00	7.315	3.764
30	24.03	7.324	3.773
40	24.07	7.337	3.786
50	24.42	7.443	3.892
60	24.43	7.446	3.895
70	24.44	7.449	3.898
80	24.46	7.455	3.904
90	24.46	7.455	3.904
100	24.48	7.462	3.911
110	24.50	7.468	3.917
120	24.50	7.468	3.917

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
bTOC - below top of casing
ags - above ground surface
min - minutes
m - metres
ft - feet

Pump Test of North Battleford Well 16: August 15, 2000

Step 1: Pump rate: 225 Igpm
Specific Capacity: 15.69 Igpm/ft (@ 60 min.)

Step 2: Pump rate: 180 Igpm
Specific Capacity: 15.27 Igpm/ft (@ 30min.)

C-89: 3 m from Well 16
C-88: 6 m from Well 16

Well 16

Static water level (m bTOC): 3.85		
Stickup (m ags):		
Elapsed Time Pumping (min)	Depth to Water (m bTOC)	Drawdown (m)
0	3.850	0.000
1	6.780	2.930
2	6.850	3.000
3	6.880	3.030
4	6.880	3.030
5	7.210	3.360
10	8.070	4.220
16	8.070	4.220
21	8.190	4.340
25	8.195	4.345
30	8.200	4.350
40	8.220	4.370
50	8.220	4.370
60	8.220	4.370
61	7.500	3.650
62	7.470	3.620
63	7.470	3.620
64	7.460	3.610
65	7.450	3.600
70	7.445	3.595
75	7.455	3.605
80	7.460	3.610
85	7.445	3.595
90	7.445	3.595

	C-89: Static water level (m bTOC): 4.03					
	C-88: Static water level (m bTOC): 4.02					
	Elapsed Time Pumping (min)	Depth to Water C-89 (m bTOC)	Drawdown (m)	Elapsed Time Pumping (min)	Depth to Water C-88 (m bTOC)	Drawdown (m)
	0	4.030	0.000	0	4.020	0.000
Step 1	1	4.720	0.690	3.5	4.540	0.520
	2	4.780	0.750	4.5	4.570	0.550
	3	4.800	0.770	10.5	4.780	0.760
	4	4.800	0.770	17	4.810	0.790
	5	4.890	0.860	22	4.840	0.820
	10	5.135	1.105	25	4.840	0.820
	16	5.160	1.130	30	4.840	0.820
	21	5.190	1.160	35	4.860	0.840
	25	5.200	1.170	40	4.860	0.840
	30	5.190	1.160	50	4.870	0.850
	40	5.210	1.180	60	4.870	0.850
	50	5.220	1.190	62.5	4.740	0.720
	60	5.220	1.190	63.5	4.740	0.720
Step 2	61	5.050	1.020	64.5	4.730	0.710
	62	5.040	1.010	70	4.735	0.715
	63	5.030	1.000	75	4.730	0.710
	64	5.025	0.995	80	4.740	0.720
	65	5.020	0.990	85	4.735	0.715
	70	5.018	0.988	90	4.740	0.720
	75	5.030	1.000			
	80	5.030	1.000			
	85	5.025	0.995			
	90	5.030	1.000			

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
ags - above ground surface
bTOC - below top of casing
min - minutes
m - metres

Pump Test of North Battleford Well 16: October 4, 2000

Pump rate: 190 Igpm
Specific Capacity: 14.30 Igpm/ft (@120 min.)

October 4, 2000			
		Static Water Level (m bTOC):	4.40
		Stickup (m ags):	
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	14.45	4.404	0.000
1	24.68	7.522	3.118
2	25.83	7.873	3.469
3	24.90	7.590	3.185
4	24.95	7.605	3.200
5	24.99	7.617	3.213
10	25.08	7.644	3.240
15	25.30	7.711	3.307
20	25.43	7.751	3.347
25	25.45	7.757	3.353
30	25.49	7.769	3.365
40	25.55	7.788	3.383
50	25.59	7.800	3.395
60	25.61	7.806	3.402
70	25.65	7.818	3.414
80	25.67	7.824	3.420
90	25.68	7.827	3.423
100	25.70	7.833	3.429
110	27.72	8.449	4.045
120	27.74	8.455	4.051

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
ags - above ground surface
bTOC - below top of casing
min - minutes
m - metres
ft - feet

Pump Test of North Battleford Well 17: July 11, 2000 and August 2, 2000

Pump rate: 173 Igpm
Specific Capacity: 14.64 Igpm/ft (@110 min.)

July 11, 2000

Static Water Level (m bTOC):			4.05
Stickup (m ags):			
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	13.28	4.048	0.000
1	23.95	7.300	3.252
2	24.56	7.486	3.438
3	24.74	7.541	3.493
4	24.78	7.553	3.505
5	24.88	7.583	3.536
10	24.99	7.617	3.569
15	25.01	7.623	3.575
20	25.03	7.629	3.581
25	25.04	7.632	3.584
30	25.05	7.635	3.587
40	25.05	7.635	3.587
50	25.06	7.638	3.591
60	25.07	7.641	3.594
70	25.08	7.644	3.597
80	25.08	7.644	3.597
90	25.09	7.647	3.600
100	25.09	7.647	3.600
110	25.09	7.647	3.600

Pump rate: 208 Igpm
Specific Capacity: 16.75 Igpm/ft (@120 min.)

August 2, 2000

Static Water Level (m bTOC):			3.71
Stickup (m ags):			
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	12.17	3.709	0.000
1	22.50	6.858	3.149
2	23.10	7.041	3.332
3	23.50	7.163	3.454
4	23.65	7.209	3.500
5	23.72	7.230	3.521
10	23.95	7.300	3.591
15	24.50	7.468	3.759
20	24.17	7.367	3.659
25	24.22	7.382	3.674
30	24.28	7.401	3.692
40	24.30	7.407	3.698
50	24.40	7.437	3.729
60	24.44	7.449	3.741
70	24.48	7.462	3.753
80	24.50	7.468	3.759
90	24.55	7.483	3.774
100	24.56	7.486	3.777
110	24.59	7.495	3.787
120	24.59	7.495	3.787

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
bTOC - below top of casing
ags - above ground surface
min - minutes
m - metres

Pump Test of North Battleford Well 17: August 17, 2000

Pump rate: 200 Igpm
Specific Capacity: 18.73 Igpm/ft (@ 120 min.)

Well 17

Static water level (m bTOC): 4.08		
Stickup (m ags):		
Elapsed Time Pumping (min)	Depth to Water (m bTOC)	Drawdown (m)
0	4.080	0.000
0.25	6.210	2.130
0.5	6.000	1.920
0.75	6.100	2.020
1	6.600	2.520
1.5	7.060	2.980
2	7.060	2.980
3	7.150	3.070
5	7.210	3.130
7	7.230	3.150
10	7.245	3.165
15	7.265	3.185
20	7.270	3.190
25	7.275	3.195
30	7.280	3.200
40	7.290	3.210
50	7.295	3.215
60	7.310	3.230
70	7.315	3.235
80	7.315	3.235
90	7.320	3.240
100	7.330	3.250
110	7.335	3.255
120	7.335	3.255

C-90: 4 m from Well 17

Static water level (m b 4.23		
Stickup (m ags):		
Elapsed Time Pumping (min)	Depth to Water (m bTOC)	Drawdown (m)
0	4.230	0.000
0.25	4.750	0.520
0.5	4.750	0.520
0.75	4.790	0.560
1	4.970	0.740
1.5	5.110	0.880
2	5.160	0.930
3	5.220	0.990
5	5.270	1.040
7	5.300	1.070
10	5.320	1.090
15	5.350	1.120
20	5.370	1.140
25	5.375	1.145
30	5.390	1.160
40	5.400	1.170
50	5.410	1.180
60	5.415	1.185
70	5.420	1.190
80	5.420	1.190
90	5.425	1.195
100	5.430	1.200
110	5.430	1.200
120	5.430	1.200

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
ags - above ground surface
bTOC - below top of casing
min - minutes
m - metres

Pump Test of North Battleford Well 17: October 3, 2000

Pump rate: 187 Igpm
Specific Capacity: 18.89 Igpm/ft (@120 min.)

October 3, 2000

Static Water Level (m bTOC):			4.60
Stickup (m ags):			
Elapsed Time Pumping (min)	Depth to Water (ft bTOC)	Depth to Water (m bTOC)	Drawdown (m)
0	15.10	4.602	0.000
1	23.30	7.102	2.499
2	23.80	7.254	2.652
3	24.00	7.315	2.713
4	24.10	7.346	2.743
5	24.17	7.367	2.765
10	24.65	7.513	2.911
15	24.70	7.529	2.926
20	24.74	7.541	2.938
25	24.80	7.559	2.957
30	24.80	7.559	2.957
40	24.82	7.565	2.963
50	24.85	7.574	2.972
60	24.86	7.577	2.975
70	24.89	7.586	2.984
80	24.90	7.590	2.987
90	24.70	7.529	2.926
100	24.80	7.559	2.957
110	24.90	7.590	2.987
120	25.00	7.620	3.018

Igpm - imperial gallons per minute
Igpm/ft - imperial gallons per minute per foot of drawdown
ags - above ground surface
bTOC - below top of casing
min - minutes
m - metres
ft - feet

APPENDIX B:

Microbiological Analysis

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.

1) <u>Why Use a BART™ Test?</u>

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 upwards 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).

2) 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

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.

BART™ Interpretation Chart

BART Type		1	2	3	4	5	6	7	8	9	10
IRB RED CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction Codes	6.0	5.0	4.0	3.6	3.0	2.0	2.0	2.0	1.0	1.0
SRB BLACK CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction Codes	6.0	5.0	4.6	4.0	3.6	3.0	2.0	2.0	1.0	1.0
HAB BLUE CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction Code	6.6	5.6	3.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0
DN GREY CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction (FO)	6.6	5.0	3.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0
SLYM GREEN CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction Codes	6.6	5.6	4.6	3.0	2.6	2.0	1.0	1.0	1.0	1.0
FLOR YELLOW CAP	Time Lag (days)	1	2	3	4	5	6	7	8	9	10
	Reaction Codes	6.0	5.0	4.0	3.6	3.0	2.0	2.0	2.0	1.0	1.0
Possible Log Population (PLP)		6.6	6.0	5.6	5.0	4.6	4.0	3.6	3.0	2.0	1.0
colony forming units per ml (cfu/ml)		5,000,000	1,000,000	500,000	100,000	50,000	10,000	5,000	1,000	100	10

Aggressivity:	high	medium	low

Reaction Code Summary:

IRB BART™

BC- Brown cloudy
BG-Brown gel
BL-Blackened
BR-Brown ring
CL-Clouded growth
FO-Foam
GC-Green cloudy
RC-Red; slightly cloudy

SRB BART™

BB-Blackened base
BT-Blackened top
BA-Blackened base and top

HAB BART™

UP-Bleaching from bottom up
DO-Bleaching from top down

SLYM BART™

DS-Dense slime
SR-Slime ring around ball
CP-Cloudy layered plates
CL-Cloudy growth
BL-Blackened liquid
TH-thread-like strands
PB-Pale blue glow (UV)

DN BART™

FO-Foam around ball

FLOR BART™

PB-Pale blue glow (UV)
GY-Greenish-yellow glow (UV)

Obtained from www.dbi.sk.ca; May 2000

August 2000 Glycolic Acid UAB™
North Battleford Well's 16 & 17[1]

Microbiological Testing Results

The microbiological testing involved collecting 250 ml water samples at 3, 10, 30, 60 and 120 minutes into a 2 hour pump test. The BART™ biodetectors were used to determine the presence and aggressivity of heterotrophic aerobic bacteria (HAB), iron related bacteria (IRB), sulfate reducing bacteria (SRB), slime forming bacteria (SLYM), and denitrifying bacteria (DN) around each well.

Well 16

The BART™ results indicate that the aggressivity of the bacteria around the well remains high, however the treatment did result in a one order of magnitude decrease in the aggressivity of the heterotrophic aerobic bacteria close to and further away from the well. A one to five order of magnitude decrease in SRB aggressivity further away from the well was also observed two months after treatment.

Well 17

The BART™ results indicate that the aggressivity of the IRB, SRB and SLYM bacteria around the well remains high, with the HAB and DN bacteria only moderately (medium) aggressivity. The UAB™ treatment saw no significant improvement in the biological aggressivity around the well except for a 3 order of magnitude decrease in the sulfate reducing bacteria further away from the well. This would indicate that the treatment was effective at reducing the anaerobic bacteria aggressivity further away from the well.

Discussion of Findings

The biological results indicated that the UAB™ (glycolic & sulfamic Acid version) treatment was effective at reducing the aggressivity of the SRB further away from both wells, and the HAB close to and further away from Well 16. Further BART testing will need to be performed at regular intervals (recommend every 3 months) to further determine the long term effectiveness of this version of the UAB™ treatment to reduce the biological aggressivity of the HAB and SRB further away from the wells.

[1] **Written by: Brent A. Keevill, M.Sc., P.Eng., Droycon Bioconcepts Inc, October 26, 2000**

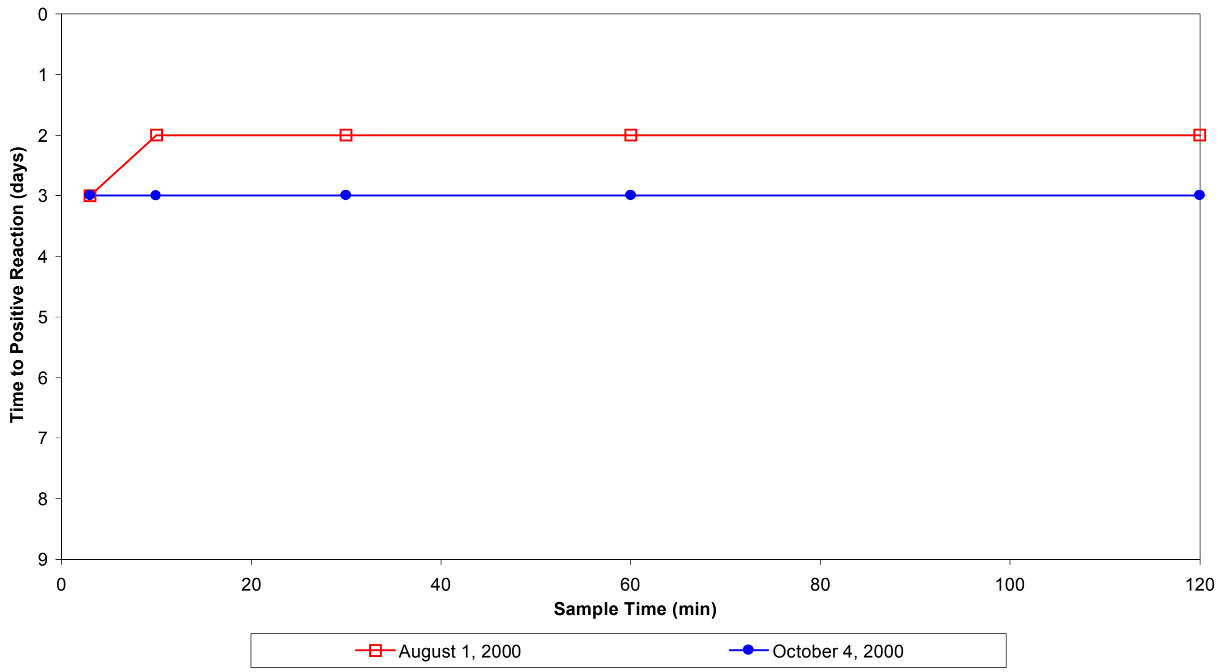
Biological Activity Reaction Tests (BART™)

North Battleford Well 16 & 17 UAB™ (Glycolic Acid) Treatment Results
Pre-Treatment (August 1 & 2, 2000) and Post Treatment (October 3 & 4, 2000)

BART Analysis	Sample Time (minutes)	Well 16				Well 17			
		August 1, 2000 (pre)		October 4, 2000 (post)		August 2, 2000 (pre)		October 3, 2000 (post)	
		dd/rx	Aggressivity	dd/rx	Aggressivity	dd/rx	Aggressivity	dd/rx	Aggressivity
HAB	3	3 DO	Medium	3 DO	Medium	3 DO	Medium	2 DO	High
	10	2 DO	High	3 DO	Medium	3 DO	Medium	3 DO	Medium
	30	2 DO	High	3 DO	Medium	2 DO	High	3 DO	Medium
	60	2 DO	High	3 DO	Medium	4 DO	Medium	3 DO	Medium
	120	2 DO	High	3 DO	Medium	4 DO	Medium	4 DO	Medium
IRB	3	2 CL	High	2 CL	High	3 CL, FO	High	2 CL	High
	10	3 CL	High	2 CL	High	3 FO	High	2 CL	High
	30	3 FO	High	2 CL	High	3 CL	High	2 CL	High
	60	3 FO	High	2 CL	High	3 CL, FO	High	3 Cl, FO	High
	120	5 BR	Medium	2 CL	High	4 CL, FO	High	4 CL, FO	High
SRB	3	4 BB	High	4 BT	High	4 BT	High	4 BT	High
	10	5 BT	High	5 BT	High	5 BT	High	4 BT	High
	30	5 BT	High	5 BB	High	5 BT	High	4 BT	High
	60	5 BT	High	10BB	Low	5 BT	High	4 BT	High
	120	9 BB	Low	10 BB	Low	4 BT	High	7 BB	Medium
SLYM	3	1 CL, CP	High	2 CL	High	2 CL, CP	High	2 CL	High
	10	2 CL	High	2 CL	High	2 CL	High	2 CL	High
	30	2 CL	High	2 CL	High	2 CL	High	2 CL	High
	60	2 CL	High	2 CL	High	2 CL	High	2 CL	High
	120	2 CL, CP	High	2 CL	High	3 CL	High	2 CL	High
DN	3	2 FO	High	2 FO	High	3 FO	Medium	2 FO	High
	10	2 FO	High	3 FO	Medium	3 FO	Medium	3 FO	Medium
	30	3 FO	Medium	3 FO	Medium	6 FO	Low	3 FO	Medium
	60	5 FO	Low	3 FO	Medium	3 FO	Medium	3 FO	Medium
	120	3 FO	Medium	3 FO	Medium	6 FO	Low	3 FO	Medium

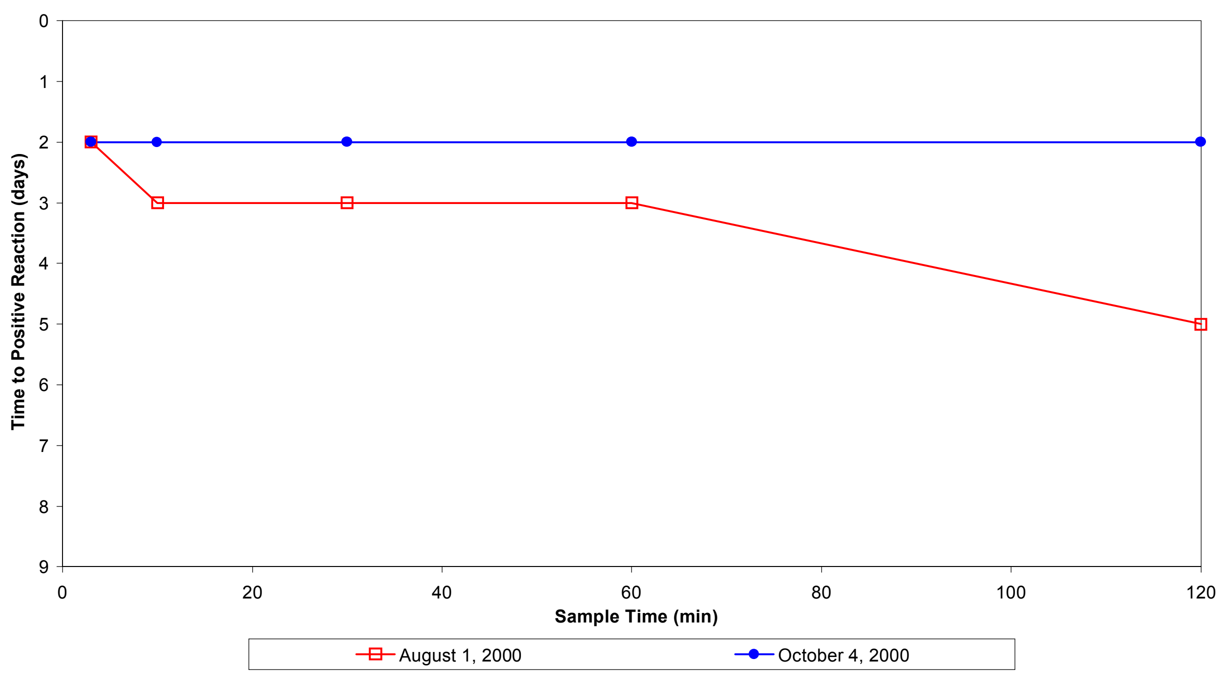
Note: see BART™ Interpretation Chart for description of reaction codes

City of North Battleford: Well 16
HAB-BART™ Results

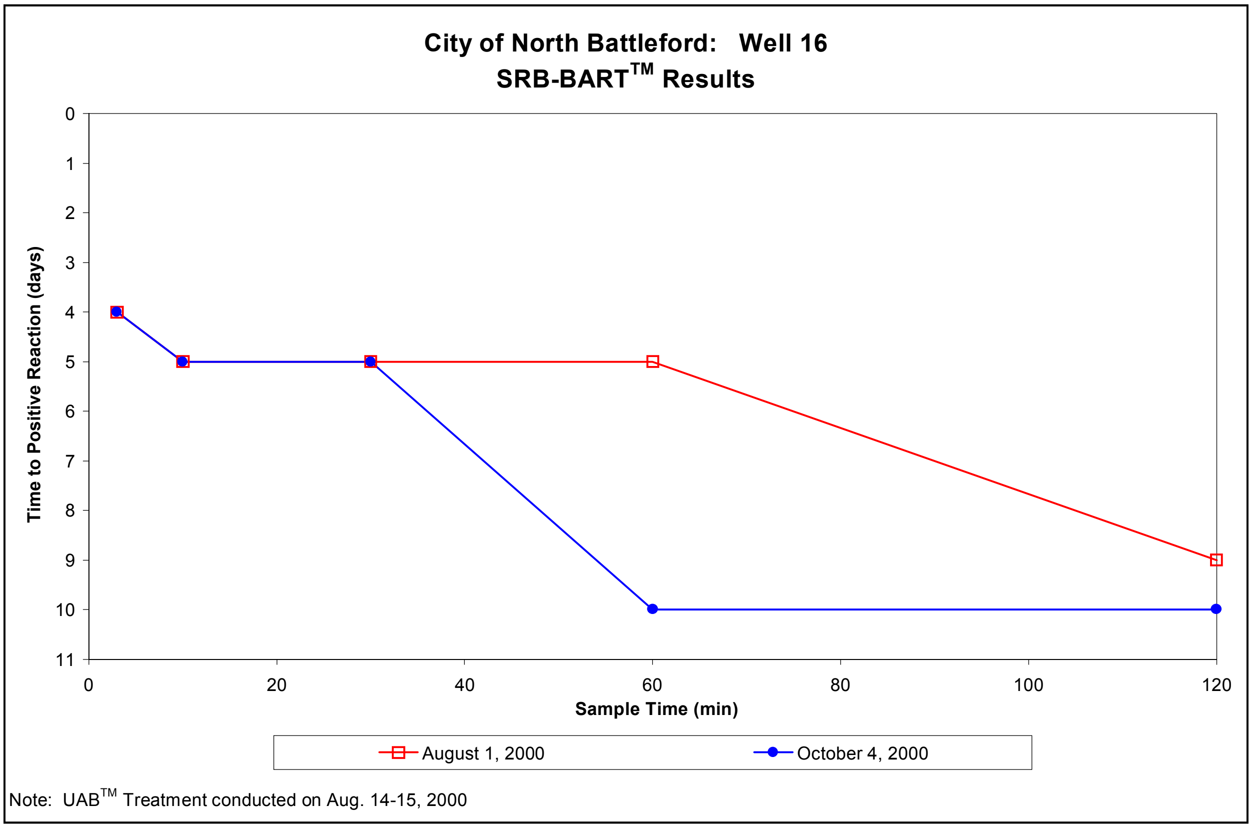


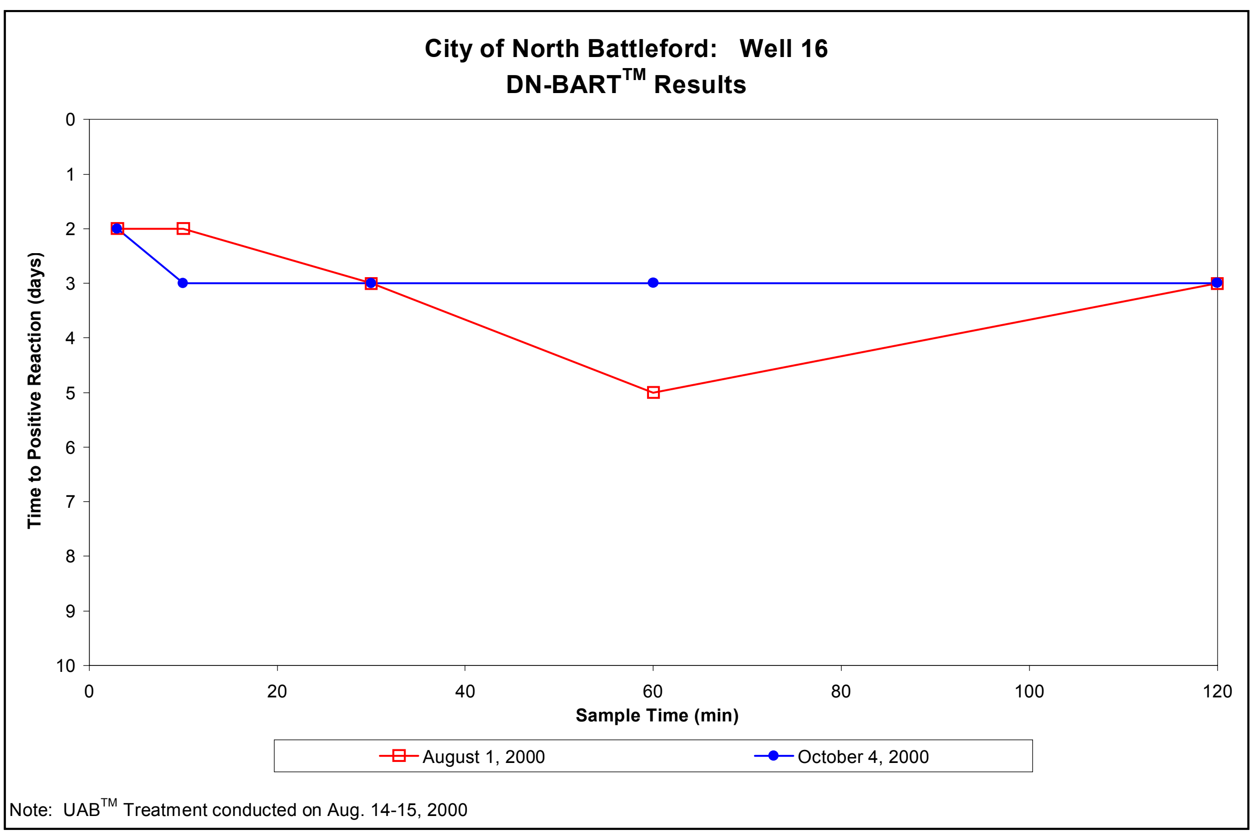
Note: UAB™ Treatment conducted on Aug. 14-15, 2000

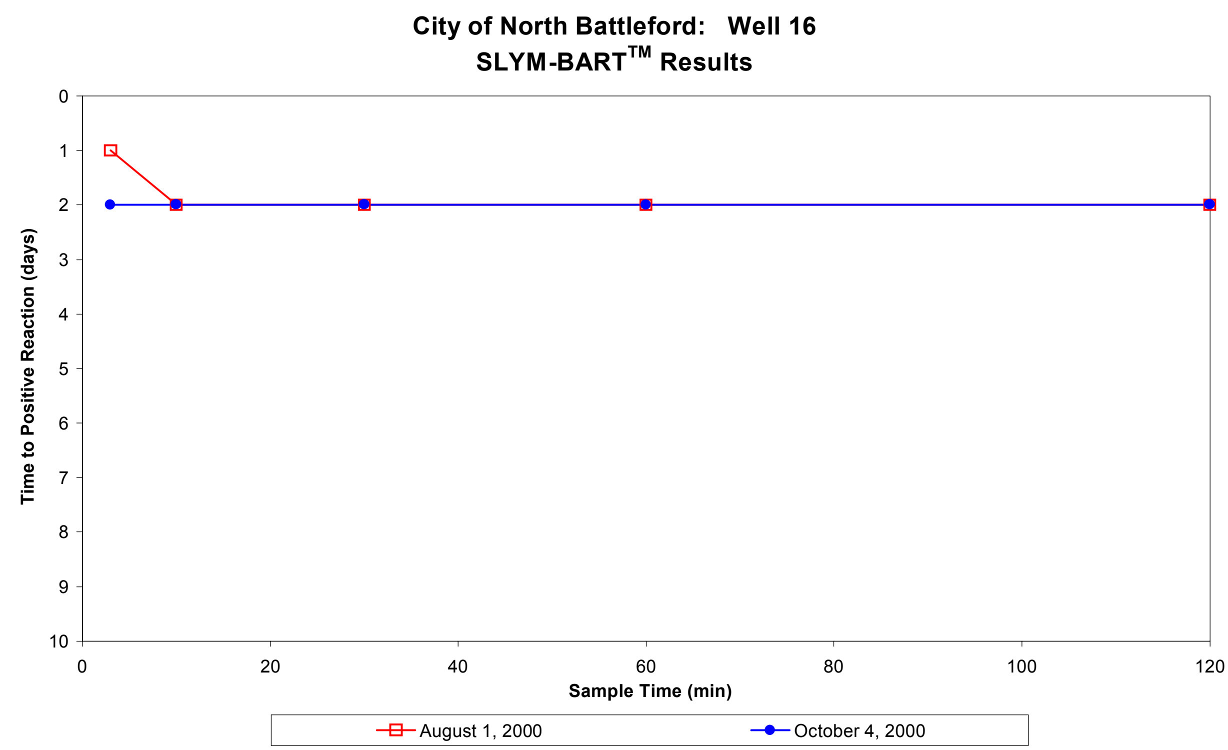
City of North Battleford: Well 16
IRB-BART™ Results



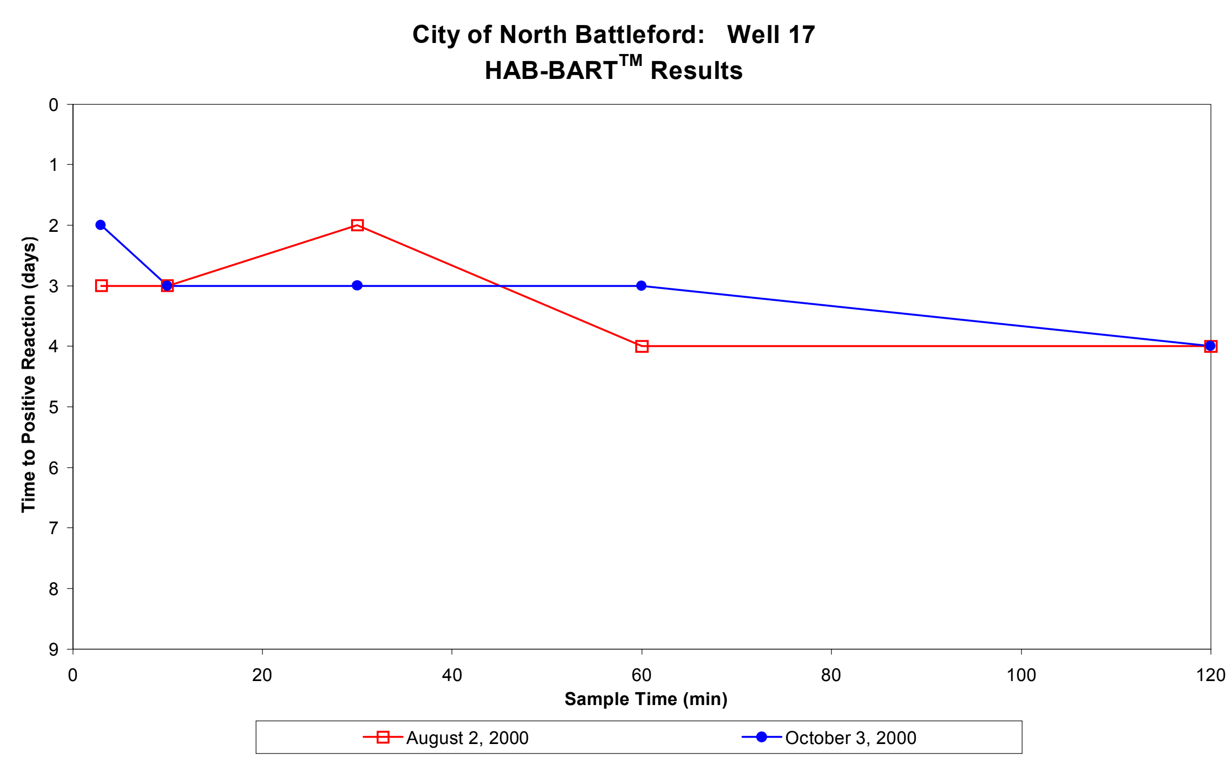
Note: UAB™ Treatment conducted on Aug. 14-15, 2000


City of North Battleford: Well 16
SRB-BART™ Results
Time to Positive Reaction (days)
0
1
2
3
4
5
6
7
8
9
10
11
0
20
40
60
80
100
120
Sample Time (min)
August 1, 2000
October 4, 2000
Note: UAB™ Treatment conducted on Aug. 14-15, 2000

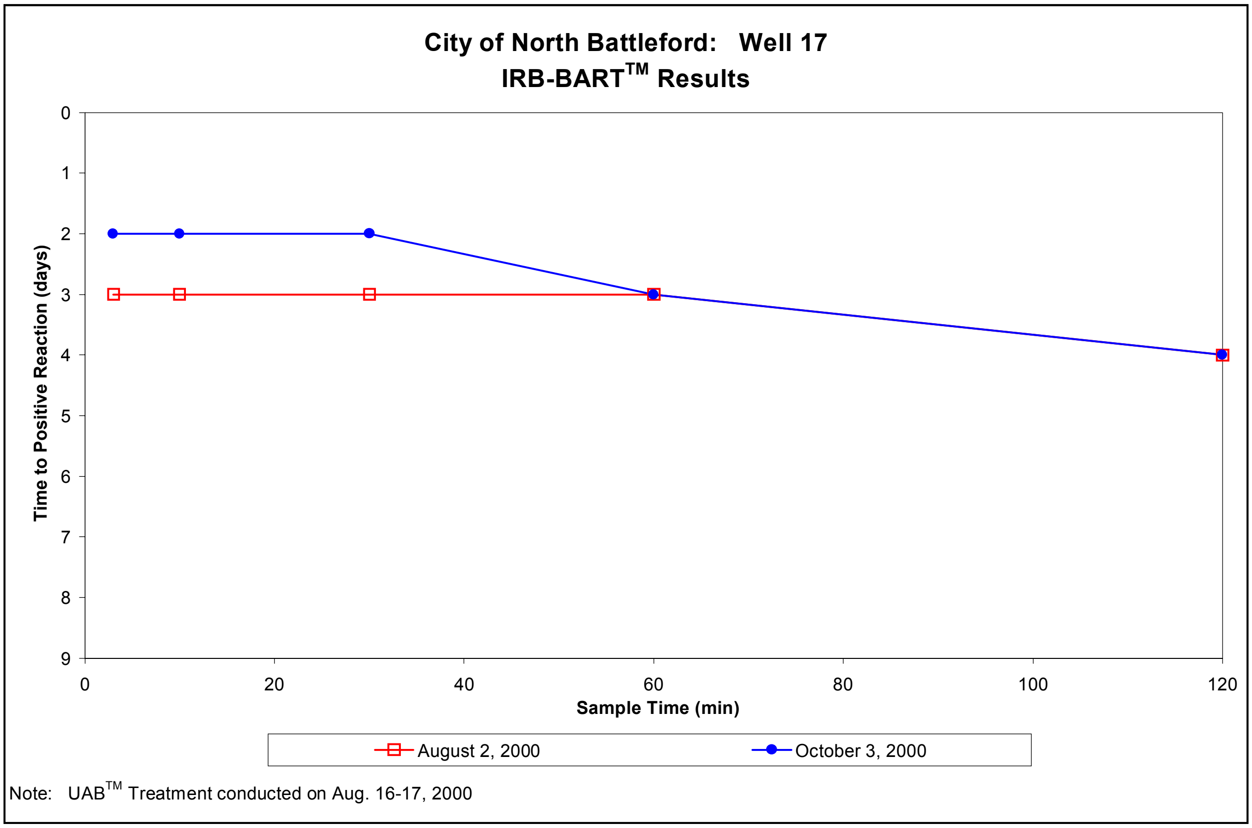

City of North Battleford: Well 16
DN-BART™ Results
Time to Positive Reaction (days)
0
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
Sample Time (min)
August 1, 2000
October 4, 2000
Note: UAB™ Treatment conducted on Aug. 14-15, 2000

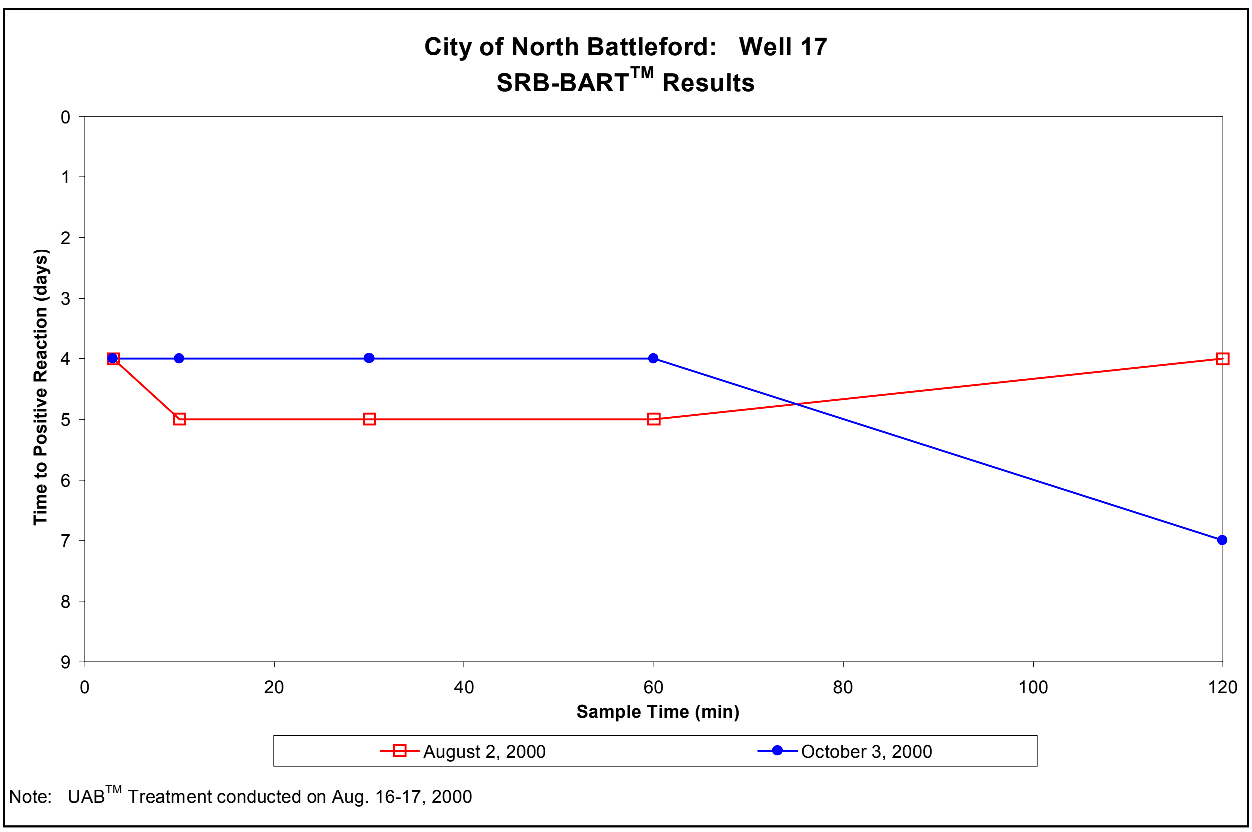


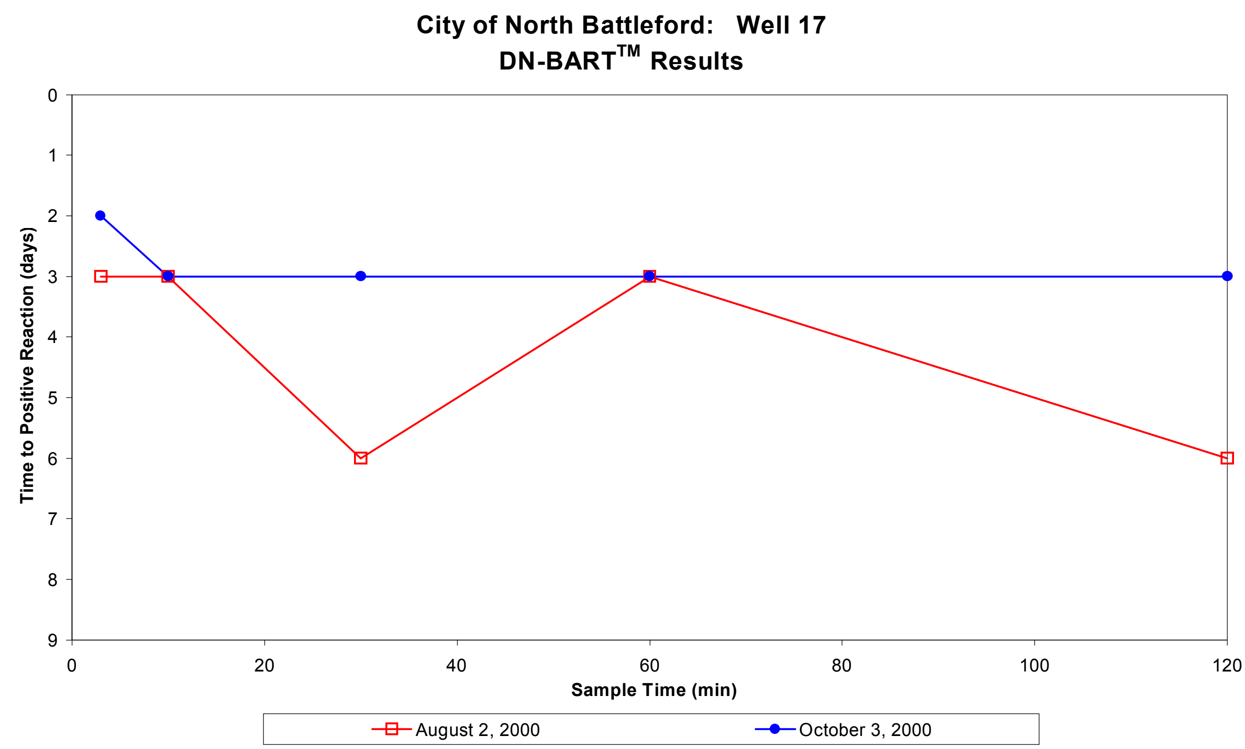
Note: UAB™ Treatment conducted on Aug. 14-15, 2000



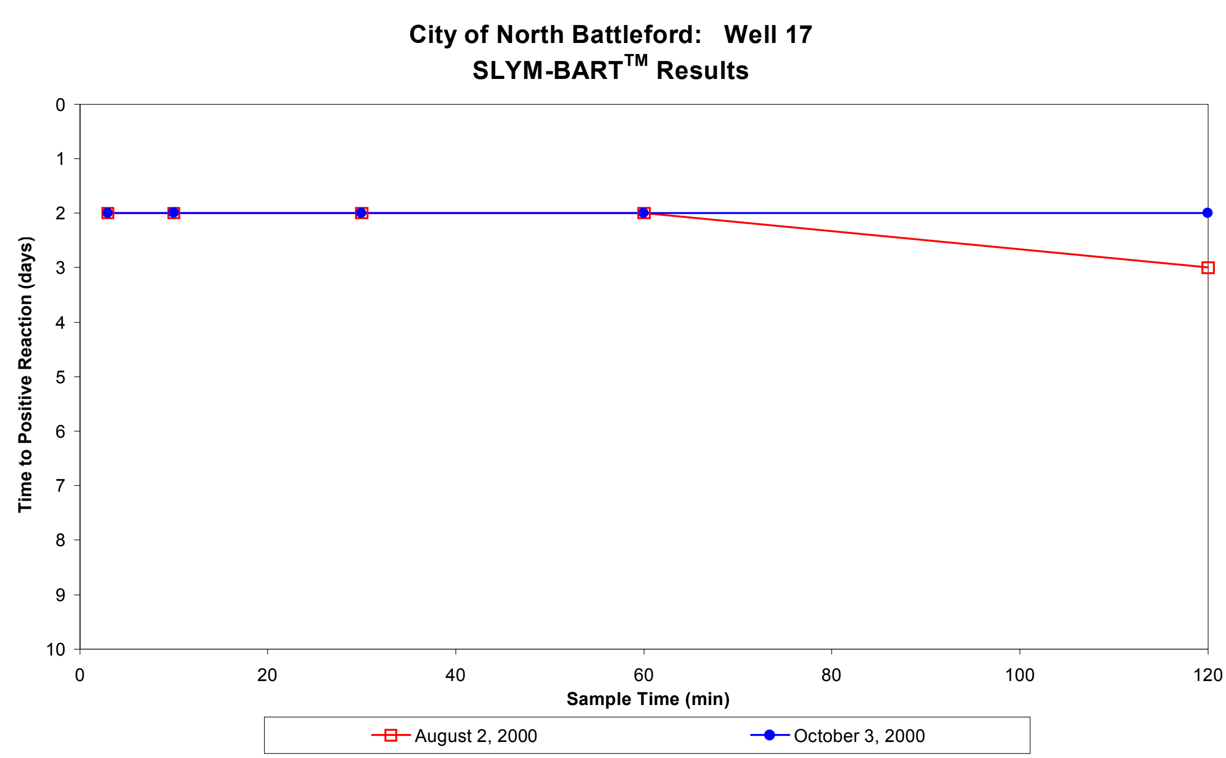
Note: UAB™ Treatment conducted on Aug. 16-17, 2000


City of North Battleford: Well 17
IRB-BART™ Results
Time to Positive Reaction (days)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
Sample Time (min)
August 2, 2000
October 3, 2000
Note: UAB™ Treatment conducted on Aug. 16-17, 2000


City of North Battleford: Well 17
SRB-BART™ Results
Time to Positive Reaction (days)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
Sample Time (min)
August 2, 2000
October 3, 2000
Note: UAB™ Treatment conducted on Aug. 16-17, 2000



Note: UAB™ Treatment conducted on Aug. 16-17, 2000



Note: UAB™ Treatment conducted on Aug. 16-17, 2000