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EXECUTIVE SUMMARY

The City of North Battleford Well Rehabilitation Project was undertaken to investigate the extent and nature of biofouling in the City of North Battleford well field and to advise on appropriate well maintenance and well rehabilitation techniques. A contribution agreement for this project was established between the Prairie Farm Rehabilitation Administration (PFRA), Droycon Bioconcepts Incorporated (DBI) and the City of North Battleford, with some funding provided by the *Canada-Saskatchewan Agri-Food Innovation Fund*. This project is divided into three phases: a diagnostics phase, a well treatment phase and a post treatment monitoring phase.

Phase 1 of this project was initiated in April 1998, consisting of a compilation of background data for Wells 15, 16 and 17, pump testing of these wells, collection of aquifer samples, water chemistry and microbiological testing of the wells and aquifer samples, and laboratory testing and analysis to evaluate the suitability of potential treatment chemicals. The results of the Phase 1 diagnostics work are provided in the report, *City of North Battleford Well Rehabilitation Project, Phase 1: Well Diagnostics Program (PFRA and DBI, June 1999)*. Based on the results of the Phase 1 diagnostics program, the well treatment phase was initiated in August 1998, to evaluate the modified Ultra-Acid Base (UAB™) treatment process on Wells 15 and 16. The detailed results of the Phase 2 well treatment evaluation are provided in this report.

The Phase 2 work consisted of applying the modified UAB™ treatment process to Wells 15 and 16. Pump tests were conducted, before and after treatment, to evaluate the effectiveness of the well treatments. After treatment, sampling and analysis of the aquifer material in vicinity of each well was also conducted to compare these results with those obtained during the Phase 1 diagnostics work. Water samples were also collected from each well for chemical and microbiological analysis. By repeating many of the diagnostic procedures conducted during Phase 1, the effectiveness of the treatment process could be evaluated by direct comparison between the identical diagnostic steps taken during each phase.

The well treatment and redevelopment work at Wells 15 and 16 was conducted from August 10-14, 1999. The modified UAB™ well treatment was applied jointly by PFRA and DBI, and the redevelopment work was conducted by Elk Point Drilling Corporation of North Battleford, Saskatchewan. These well treatments proved to be successful in increasing the specific capacity from 2.67 to 2.99 igpm/ft (*imperial gallons per minute per foot of drawdown*) at Well 15 and from 13.1 to 21.1 igpm/ft at Well 16. However, biological testing, using the Biological Activity Reaction Test (BART™) system, indicated that high aggressivity levels of nuisance-type bacteria still persisted around these wells. At Well 15, the specific capacity declined sharply shortly after treatment, which appears to verify that the biofouling around this well is fairly severe and the recent well treatment was not able to effectively remove the plugging material. At Well 16, the original specific capacity was restored, which validates the laboratory findings by DBI that suggest that the original specific capacity of a well can be restored if the specific capacity has declined by less than 40 per cent.

The post treatment diagnostic results indicate that although 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, the bacterial regrowth potential is high due to the incomplete removal of the plugging material. Therefore, 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 in order to maintain the specific capacities of these wells. 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 each well, and will signal the need for remedial action. The Phase 3 post treatment monitoring program for this project will also provide guidance for a preventative well maintenance strategy for these wells.

ACKNOWLEDGEMENTS

Project Partners:

Droycon Bioconcepts Incorporated (DBI):
We gratefully acknowledge Dr. Roy Cullimore for his technical input and guidance during the course of this project, with special thanks to Brent Keevill and Lori Johnston for their expertise in the microbiological assessment of the wells and aquifer, and for their close collaboration with PFRA staff during the field work and in the laboratory studies. The cooperation and assistance of the entire DBI staff is also greatly appreciated.

City of North Battleford :
The support and contributions to this project by Bob Berry and Ivan Katzell are gratefully acknowledged. Also, special thanks to Ivan Katzell and his staff for their cooperation and assistance during the course of this project.

Elk Point Drilling Corporation:
A special thanks to John Soloninko and Chris Hood of Elk Point Drilling Corporation for their contributions to this project. We especially appreciated the extra attention and effort given to the redevelopment of the wells after treatment.

Project Funding:

Partial funding for this project was provided by the Canada-Saskatchewan Agri-Food Innovation Fund and by the City of North Battleford.

The in-kind contributions provided by all the project partners is also gratefully acknowledged.

1.0 BACKGROUND

The City of North Battleford Well Rehabilitation Project forms part of the Sustainable Water Well Initiative (SWWI), which was created by the Prairie Farm Rehabilitation Administration (PFRA) to address concerns regarding declining well yield, water quality deterioration and reduction in well life span. The SWWI is intended to investigate a variety of physical and chemical problems that are often experienced in water wells. However, this initiative has initially focussed on the microbiological aspects of water well deterioration and rehabilitation, since this aspect is still the least understood. As a result of SWWI studies, a new treatment process for biofouled wells was developed and is currently being evaluated. This treatment process, known as Ultra Acid-Base™ (UAB™), was developed by Droycon Bioconcepts Incorporated (DBI) of Regina, Saskatchewan, in conjunction with PFRA, and a joint venture arrangement was established to field test this treatment technology.

Based on the promising results of the 1997 field test of the UAB™ treatment process on Well 15 (PFRA and DBI, 1998), the City of North Battleford Well Rehabilitation Project was created to further investigate the aquifer and wells from which the City obtains its water supply. The purpose of this project is to investigate the extent and nature of biofouling in the City of North Battleford well field and to advise on appropriate well maintenance and well rehabilitation techniques. A contribution agreement for this project was established between the PFRA, DBI and the City of North Battleford, with some funding provided by the *Canada-Saskatchewan Agri-Food Innovation Fund*. This project is divided into three phases: a diagnostics phase, a well treatment phase and a post treatment monitoring phase. The diagnostics phase of this project commenced in April 1998, and the results of the Phase 1 diagnostics work are provided in the report, *City of North Battleford Well Rehabilitation Project, Phase 1: Well Diagnostics Program (PFRA and DBI, June 1999)*.

1.1 Introduction

As part of the Phase 1 study, diagnostics work was performed on Wells 15, 16 and 17. Although diagnostic testing revealed that Well 15 had no decrease in specific capacity since treatment in October 1997, highly aggressive populations of iron related bacteria (IRB) and sulphate reducing bacteria (SRB) were present. Diagnostic testing at Well 16 revealed that this well had experienced a 43% reduction in specific capacity, and the biological activity around the well was highly aggressive. Although Well 17 had experienced no reduction in specific capacity, the aquifer sampling and testing revealed that there were highly aggressive populations of IRB present. As a result of the Phase 1 diagnostics program, Wells 15 and 16 were recommended as candidates for further investigation as part of the Phase 2 well treatment evaluation. Although Well 17 was not selected for treatment at this time, it was recommended that preventative maintenance procedures be implemented as the earliest opportunity (PFRA and DBI, June 1999).

Laboratory testing by both PFRA and DBI has resulted in improvements to the UAB™ treatment process, as described in the Phase 1 report (PFRA and DBI, June 1999). During this Phase 2 study, the modified UAB™ treatment process was field tested on Wells 15 and 16 from August 10-13, 1998. Pump tests were also performed immediately before and after treatment to evaluate the effectiveness of the well treatments. After treatment, aquifer samples were also collected in vicinity of each well and water samples were collected from the wells for chemical and microbiological analyses. The wells and test hole sites for this project are shown in Figure 1, and the detailed results of the Phase 2 well treatment evaluation are provided in this report.

FIGURE 1 **Location Plan**

2.0 WELL TREATMENT

As a result of Sustainable Water Well Initiative (SWWI) studies on microbiological plugging of water wells, a new treatment process for biofouled wells, known as Ultra Acid-Base™ (UAB™), was developed by DBI in conjunction with PFRA (PFRA and DBI, 1997). A joint venture arrangement was also established between PFRA and DBI to field test and evaluate this treatment technology. In October 1997, the UAB™ treatment process was field tested and evaluated on the City of North Battleford's Well 15. After this initial treatment, the specific capacity of Well 15 increased from 1.96 igpm/ft to 3.45 igpm/ft. Although the original specific capacity of 18 igpm/ft was not restored, this was a substantial improvement over past rehabilitation efforts performed on Well 15. Based on these promising results, a continued effort to improve the UAB™ treatment technology was undertaken jointly by PFRA and DBI. Laboratory experimentation and testing conducted by both PFRA and DBI subsequently led to improvements in the treatment process, resulting in the development of a modified UAB™ treatment process.

In this Phase 2 study, Wells 15 and 16 were selected as sites to field test the modified UAB™ treatment process. Well 15 had been previously treated with the original UAB™ treatment process with promising results, and it was hoped that a second treatment would yield further improvements. The Phase 1 diagnostics testing revealed that Well 16 had experienced a specific capacity reduction of 43% reduction since its installation in 1995, and therefore, would also benefit from a well treatment. Laboratory testing of the UAB™ treatment process by DBI indicated that once a well has lost more than 40% of its original specific capacity, it becomes very difficult to restore the well to its original condition (Keevill, March 1999). By conducting a treatment on Well 16 at this time, with an improved UAB™ treatment process, it was hoped that it would be possible to restore the well's original specific capacity. A discussion of the UAB™ treatment process and the results of the treatments on both Wells 15 and 16 is provided in the following sections.

2.1 Ultra-Acid Base (UAB™) Treatment Process

The Ultra-Acid Base (UAB™) treatment process was developed by DBI in 1996 to treat biofouled wells, and ongoing testing and evaluation by both DBI and PFRA has led to improvements in the treatment process. This process uses a combination of chemicals and hot water to remove the plugging biofilms from both the sand pack and aquifer material around the well. Heat (hot water) is used to facilitate the destruction of the biofilms, which then allows the treatment chemicals to more effectively penetrate the regions of severe plugging around the well intake area. A combination of chemicals is used during the various stages of the UAB™ treatment process to alter the pH environment around the well intake area, from about 2.5 to 9.5. This shift of 7 pH units over a short period traumatizes the bacteria, allowing for a more effective disruption and dispersion of the biofilms and bioaccumulates. This combination of heat and chemistry, used as part of the UAB™ treatment process, will disrupt the biofilms and keep the disrupted plugging material in suspension so it can be more effectively removed. A more detailed description of the development and theory of the UAB™ treatment process is provided in the report, *Development of Ultra Acid-Base (UAB™) Water Well Treatment Technology (PFRA and DBI, 1997)*.

The Ultra-Acid Base (UAB™) treatment process has been modified to reflect the results of the laboratory experimentation conducted jointly be PFRA and DBI. This modified treatment process was used on both Wells 15 and 16 during the Phase 2 well treatment work in August 1998, and consists of three distinct phases.

The *first phase* involves a screen clean-up stage and an initial **SHOCK** phase using muriatic acid (3 – 5% by volume), CB-4 wetting agent (1% by volume) and a water solution heated to about 80°C. The amount of solution required is 1.5 times the static water column volume of the well. The purpose of this phase is to remove screen incrustations and to open up the void spaces in the adjacent sand pack that are plugged or restricted with biological slimes. This first step opens up more pathways and preheats the area around the screen. A wire brush is also lowered up and down the screen surface to help clean out the screen slots, if required.

The *second phase* is designed to **DISRUPT** the plugged or biofouled zone. This is accomplished by inducing a pH "flip-flop", by altering the pH from 2.5 to 9.5, 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 is obtained by first using muriatic acid (4 % by volume) to obtain a pH of 2.5, and then using sodium hypochlorite to obtain a pH of 9.5. Both steps involve using CB-4 (1% by volume), a hot water solution (approximately 5600 litres for each well), surging and pumping clean. An overnight contact time is required to dissolve iron and manganese oxides that have collected in the biofilms and encrustations.

The *third phase* is the **DISPERSE** phase. This 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), bailing (bailer or air lifting) and pumping. The main purpose of surging (re-developing) the well is to suspend the disrupted plugging material so it can be removed by air-lift pumping. The final step is to pump the treated water from the well until the water is clear and the pH has returned to its original level. Alternating the pumping rate can also assist in causing additional detachment of plugging material and improved rehabilitation.

3.0 WELL TREATMENT EVALUATION

In order to evaluate the effectiveness of the UAB™ treatments applied at Wells 15 and 16, pump tests were conducted on each well immediately before and after treatment. Secondly, drilling and sampling of the aquifer material in vicinity of the wells was conducted to determine the extent and degree of biofouling after treatment. Thirdly, water samples were collected from each well for water chemistry and microbiological analysis. The results of the post treatment diagnostic testing, along with a comparison to the pre-treatment conditions, are described in the following sections.

3.1 Specific Capacity Measurements

A two-hour pump test was conducted on each well, immediately before and after treatment to evaluate the effectiveness of the well rehabilitation work. During each test, the well was pumped at a constant rate and the water level was recorded at regular time intervals. The detailed pump test results are provided in Appendix A.

3.1.1 Well 15

Well 15 had been treated with the original UAB™ treatment process in October 1997, as described in the report, *City of North Battleford Well 15, 1997 Field Test of UAB™ Water Well Treatment Technology* (PFRA and DBI, 1998). In 1990, Well 15 had an original specific capacity of 18 igpm/ft, at a pumping rate of 360 igpm. Prior to treatment in October 1997, the specific capacity had declined by about 90%, to 1.96 igpm/ft, at a pumping rate of 70 igpm. After treatment, the specific capacity increased to 2.87 igpm/ft, and by December 1997 had reached a high of 3.45 igpm/ft, as shown in Figure 1. Although this was only about 20% of the original

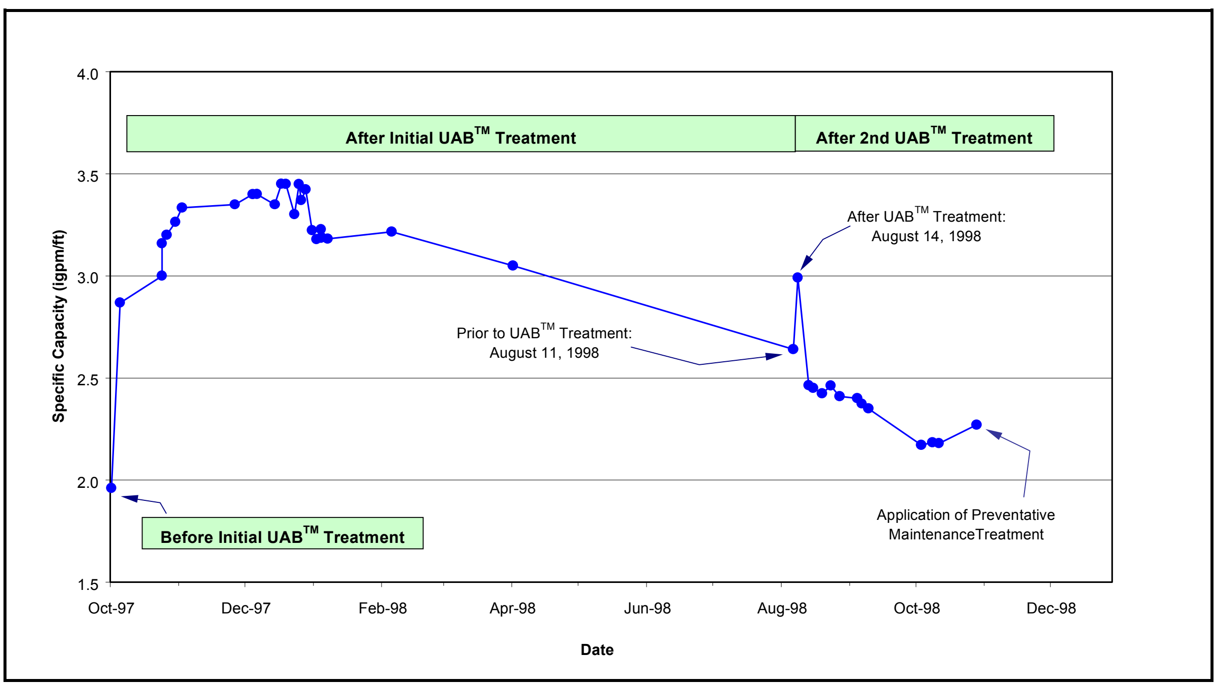

FIGURE 2 Well 15: Specific Capacity Measurements

specific capacity, it was a 76% improvement over the pre-treatment condition. During the Phase 1 diagnostic testing in April 1998, the specific capacity of Well 15 had declined slightly to 3.09 igpm/ft, and just prior to treatment in August 1998, the specific capacity had further declined to 2.67 igpm/ft. After treatment, the specific capacity increased slightly to 2.99 igpm/ft, as shown in Figure 1. These results seem to suggest that the biofouling around the well is fairly extensive and the treatment was not able to effectively remove the plugging material beyond the immediate radius of the well. Subsequent post treatment measurements also revealed that the specific capacity declined rapidly after treatment. However, a preventative maintenance treatment conducted by the City of North Battleford in November 1998, appeared to stabilize the specific capacity at about 2.3 igpm/ft.

3.1.2 Well 16

Well 16 was installed in 1995 with an original specific capacity of 20 igpm/ft, and until the Phase 1 diagnostic testing was conducted in April 1998, had not been evaluated with respect to specific capacity. On April 15, 1998, a two-hour pump test, at a constant rate of 200 igpm, revealed that the specific capacity had declined 43% over the past three years to 11.44 igpm/ft, as shown in Figure 2. A pump test conducted in August 1998, prior to treatment, indicated that the specific capacity had increased slightly to 13.1 igpm/ft. After treatment, the specific capacity improved to 21.1 igpm/ft, and by November 1998, stabilized at about 19 igpm/ft. These results appear to validate the laboratory findings by DBI that suggest if treatment of a biofouled well occurs before its specific capacity declines by more than 40 per cent, the ability to restore the original specific capacity of a well is greatly improved (Keevill, March 1999).

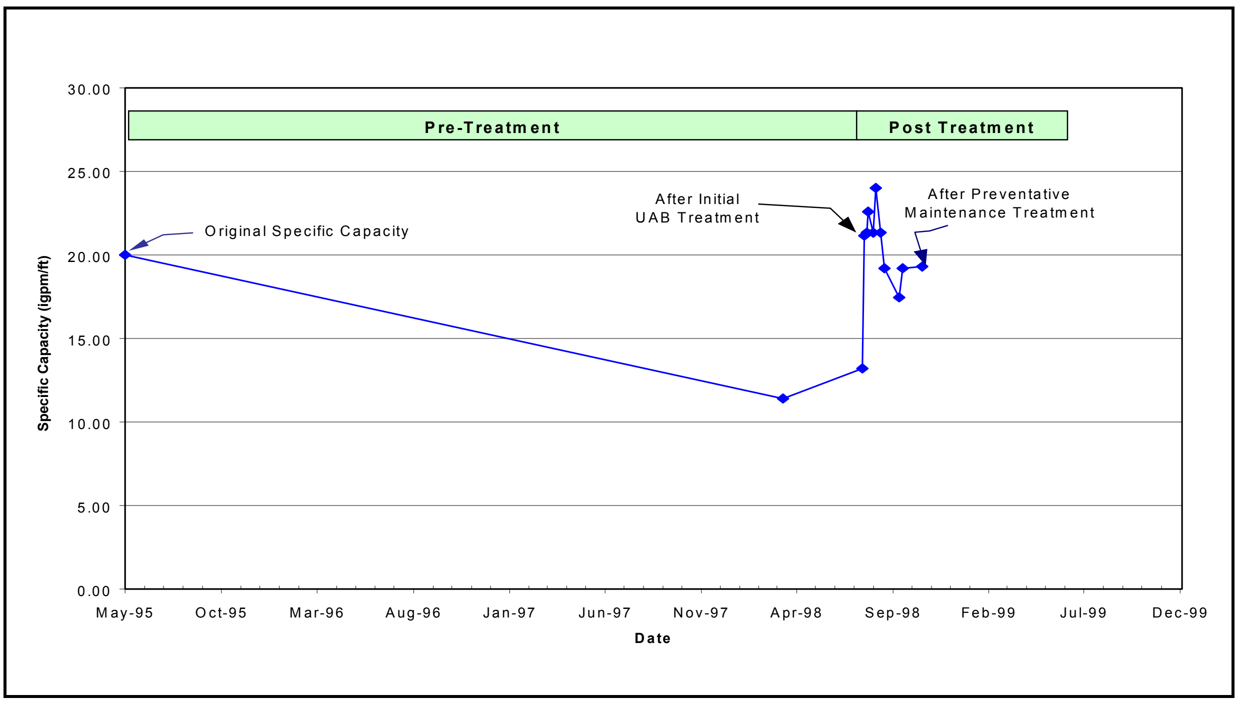

FIGURE 3 WELL 16: Specific Capacity Measurements

3.2 Drilling and Aquifer Sampling

The purpose of the drilling and aquifer core-sampling was to determine the extent and degree of biofouling after treatment. During the Phase 1 diagnostic testing, aquifer samples were collected in vicinity of both Wells 15 and 16. In November 1998, about 3 months after treatment, aquifer samples were again collected to evaluate the effect of the UAB™ treatment. The post treatment cores were extracted 0.76 metres from the pre-treatment cores at Well 15 and 0.6 metres from the pre-treatment cores at Well 16. The test hole drilling was conducted with a cable tool rig and continuous aquifer samples were collected in brass liners, using a drive-in sampling barrel. Continuous aquifer sampling commenced once the saturated level of the aquifer was encountered and continued to the bottom of the screen level. The aquifer sand samples were collected and delivered to Regina for laboratory analysis, to be conducted by both PFRA and DBI. The test hole logs are included in Appendix B. Piezometers were not installed in these test holes, since piezometers were installed at each well site during the Phase 1 work. These piezometers will be used for monitoring during the post treatment phase (Phase 3) of this project.

3.2.1 Chemical Analysis of Aquifer Sand Samples

The aquifer sand samples were analyzed by DBI for iron and manganese concentrations using US EPA method 3051. This laboratory method uses acid digestion of a representative sample from each core sample and inductively coupled plasma (ICP) to determine the iron and manganese concentrations. Table 1 provides the ICP chemistry data obtained from the aquifer sand samples before and after treatment.

Chemical Parameter (mg/kg)	Well 15				Well 16			
	Distance = 3m		Distance = 6m		Distance = 3m		Distance = 6m	
	C85 Pre-Treatment	C91 Post Treatment	C86 Pre-Treatment	C92 Post Treatment	C89 Pre-Treatment	C93 Post Treatment	C88 Pre-Treatment	C94 Post Treatment
Iron	7440	5530	6290	6160	5900	8190	3800	5600
Manganese	277	187	195	187	170	221	80.4	156

TABLE 1 ICP Chemistry Results from Core Samples

The post treatment cores were extracted about three months after treatment, in order to determine the effect the treatment had on the chemical and biological components in the aquifer material surrounding the wells. At Well 15, the iron and manganese levels around the well decreased after treatment, while around Well 16 these levels increased. These findings indicate that Well 15 may have a higher concentration of iron and manganese immediately around the well, and these levels were reduced after treatment. On the other hand, Well 16 may have higher levels of iron and manganese further from the well, which were mobilized and moved towards the well after treatment. Another possibility is that the highly aggressive iron-related bacteria (IRB) around Well 15 were starved for iron after treatment and consumed more iron than the less aggressive IRB around Well 16 (Keevill, December 1999).

The thin black coal bands in the aquifer core samples were also analyzed, and iron concentrations of 28,500 mg/kg and manganese concentrations of 625 mg/kg were measured. The high levels of iron in the coal seams represent a food source for the iron-related bacteria. Laboratory experimentation has shown that the UAB™ treatments with hydrochloric (muriatic) acid can dissolve some of this coal, which could have resulted in the elevated iron and manganese levels at Well 16 after treatment due to less bio-filtration by the bacteria.

3.3 Water Chemistry

Water samples were collected during this Phase 2 study, immediately before and three months after treatment, as shown in Table 2. These water samples were collected at the end of a two-hour pump test conducted on both Wells 15 and 16. The water quality analyses results, before and after treatment, were then compared to determine any changes in water quality.

Water Chemistry Parameter	Well 15		Well 16	
	Pre-Treatment Aug. 10, 1998	Post Treatment Nov. 2, 1998	Pre-Treatment Aug. 11, 1998	Post Treatment Nov. 3, 1998
pH	7.77	7.22	8.3	7.4
Iron (mg/L)	2.15	2.12	1.54	1.54
Manganese (mg/L)	0.77	0.63	0.563	0.611
Total Hardness (mg/L $CaCO_3$)	250	250	180	195
Conductivity (mS/cm)	0.628	0.654	0.403	0.413
Total Dissolved Solids (mg/L)	314	327	201	206
Turbidity (FTU's)	30	37	7	6
Colour (ptco units)	147	202	32	73
Nitrate (mg/L)	0.03	0.02	0.03	0.02
Sulfates (mg/L)	140	105	54	56
Nitrogen (mg/L)	0.46	0.28	0.25	0.18
Phosphorus (mg/L)	0.02	0.01	0.72	0.3

TABLE 2 Water Chemistry Results from Wells (after 120 minutes of pumping)

After treatment, there was no significant change in the overall water quality at Wells 15 and 16. However, there was a slight reduction in the iron, manganese and sulphate levels at Well 15. This may be due to the treatment process, which could have removed some of the minerals that may have collected and concentrated in the biofilm surrounding this well. At Well 16, a slight decrease in the phosphorous level was measured after treatment. However, this phosphorous level is still much higher than that measured at Well 15. This higher level is somewhat expected, since Well 16 is adjacent to the North Saskatchewan River, and it is highly probable that these higher nutrient levels available from the river water will also have a greater biological impact on Well 16, than wells located further from the river.

3.4 Microbiological Testing

Water samples for microbiological analysis were collected during this Phase 2 study, immediately before and three months after treatment. These water samples were collected during a two-hour pump test conducted on Wells 15 and 16. The microbiological analyses results, before and after treatment, were then compared to determine changes in biological activity, and thereby, evaluate the effectiveness of the well treatments. Aquifer samples were also collected for microbiological analysis to determine the biological activity in the aquifer material surrounding each well.

All the analyses for biological activity were conducted by using the Biological Activity Reaction Test (BART™), which determines the presence and aggressivity of the bacteria causing the biofouling problems. The BARTs™ used for the microbiological testing of both the water and aquifer samples were the HAB-BART™ (for heterotrophic bacteria), the IRB-BART™ (for iron related bacteria), the SRB-BART™ (for sulphate reducing bacteria), the SLYM-BART™ (for slime forming bacteria) and the DN-BART™ (for denitrifying bacteria). A brief discussion of the microbiological testing results, for both the water and aquifer sand samples, is provided in the following sections.

3.4.1 BART™ Analysis of Water Samples

Water samples for microbiological analysis were collected, immediately before and three months after treatment. These water samples were collected at 1, 3, 5, 10, 15, 30, 60, 90 and 120 minutes, during a two-hour pump test on each well. A generalized summary of the results are shown in Table 3, and the more detailed data and a graphical representation of the results are provided in Appendix C.

BART™	Well 15		Well 16	
	Pre-Treatment August 10, 1998	Post Treatment November 4, 1998	Pre-Treatment August 11, 1998	Post Treatment November 5, 1998
HAB	medium	medium	high	low
IRB	high	high	high	medium
SRB	high	high	high	high
SLYM	high	high	high	medium
DN	medium	medium	high	low

TABLE 3 BART™ Interpretation Results from Well Sites: August and November 1998

Well 15: A general reduction in biological activity was observed after the 1997 UAB ™ treatment of this well (PFRA and DBI, 1999). BART™ testing, conducted in August 1998, indicates that the IRB and SRB bacteria are again approaching the highly aggressive levels measured prior to the initial treatment in October 1997. The results of the HAB and DN tests indicate that the aggressivity of these bacteria is still lower than measured prior to initial treatment. During this Phase 2 study, the post treatment biological testing at Well 15 in

November 1998, revealed that the aggressivity levels of the various bacteria were similar to the pre-treatment levels measured in August 1998. From these results, it is apparent that the biological activity has not diminished, and therefore, it is recommended that a preventative maintenance program be implemented immediately to ensure that the well does not regress to the severely biofouled condition observed prior to the initial UAB™ treatment in October 1997.

Well 16: Based on BART™ analysis of water samples obtained prior to treatment in August 1998, the IRB, HAB, SRB, SLYM and DN bacteria were found to be highly aggressive, indicating that Well 16 is severely biofouled. However, post treatment BART™ results from November 1998 showed a decrease in the aggressivity level of most of the bacteria. The aggressivity level of the IRB and SLYM bacteria decreased from high to medium, while the HAB and DN bacteria decreased from high to low. The SRB remained at a high aggressivity level, although there was an increase in the reaction time, as shown in Appendix C. These results indicate that the treatment removed a significant portion of the biological plugging material around this well.

3.4.2 BART™ Analysis of Aquifer Sand Samples

The sampling of the aquifer material was used to determine the biological activity in vicinity of each well, before and after treatment. The pre-treatment samples were collected during the Phase 1 study in April 1998, and the post treatment samples were collected three months after treatment, in November 1998. At each of the test hole sites, core samples of the aquifer material were collected and the samples were then dissected in the laboratory for analysis by DBI. The biological analysis for these samples was conducted by placing 0.5 grams of aquifer sand into a BART™ sample container and adding 15 ml of sterile water. A summary of the results are provided in Table 4, with detailed results provided in Appendix C. An illustrative presentation of the BART™ data collected from the aquifer core samples, before and after treatment, was prepared by DBI. These illustrations show the degree of biofouling at different depths, and are included in Appendix C.

BART™ Analysis	Well 15				Well 16			
	Distance = 3 metres		Distance = 6 metres		Distance = 3 metres		Distance = 6 metres	
	C85 Pre-Treatment	C91 Post Treatment	C86 Pre-Treatment	C92 Post Treatment	C89 Pre-Treatment	C93 Post Treatment	C88 Pre-Treatment	C94 Post Treatment
HAB	medium	high	medium	high	low	medium	high	medium
IRB	high-med.	high	low-med.	high	high	med.-high	low	high
SRB	high	low-med.	high	medium	high-med	low	high	medium
SLYM	high	high	high	high	high	high	high	high
DN	low	high	low	high	low	med.-high	low	high

TABLE 4 Bacterial Aggressivity Levels in Aquifer Core Samples

A comparison of the core sample test results from both well sites indicates that, after treatment, there appears to be no overall decrease in the severity of the biofouling from 3 to 6 metres at each well site (see Table 4). Actually, post treatment results indicate that the HAB and DN bacteria have increased at both sites, suggesting that these bacteria have successful re-colonized. The SRB are the only bacteria that have shown a general reduction after treatment, at both sites. This implies that although there may have been some improvement in specific capacity at each well site, especially Well 16, the biological aggressivity has not decreased at distances up to 6 metres from each well. Therefore, preventative maintenance procedures should be implemented at the earliest opportunity to prevent biological plugging, which may cause a reduction in specific capacity in the near future.

3.5 Laser Particle Counting Results

Laser particle counting (LPC) analysis was conducted by DBI (Keevill, December 1999) to provide some insight into the ability of the treatment process to breakdown biological matter into particle sizes that can be removed from the aquifer matrix. The laser particle counting results on water samples obtained from Wells 15 and 16, before and after treatment are provided in Appendix D.

Laser particle counting is a useful tool to determine the relative sizes and numbers of particles present in water, over the size range of 0.4 to 120 microns. These number and size counts are used to calculate the total suspended solids (TSS), and a mean size calculation provides an indication of the form of these particles. It is postulated that laser particle counting can also signal the severity of biological plugging by providing an indication of the size of the particles passing through the void spaces in an aquifer. For example, if primarily small particles are present in the water, this may indicate a more restrictive environment where the void spaces in the aquifer have been reduced, which would be a symptom of a rapidly plugging well.

<u>Well 15:</u> Prior to the initial UAB™ treatment in October 1997, the mean particle size of a representative water sample was 2.82 microns. After this initial treatment, these particles increased to a mean size of 5.21 microns, an indication that the void spaces were opened up during treatment, allowing larger particles to migrate into the well. On April 6, 1998, six months after treatment, the mean particle size was 2.77 microns. However, about 60% of these particles were in the 8 to 16 micron range compared to only 19% before treatment (PFRA and DBI, June 1999). These results suggest that the larger void spaces created during the initial treatment were still allowing the larger physical and biological particulate matter to migrate into the well.

Prior to the second UAB™ treatment in August 1998, the mean particle size had been reduced to 2.17 microns, with all particles less than 8 microns in size (Table 5). This implies that the void spaces in the aquifer have been further reduced since the initial treatment. After the second treatment, the mean particle size had further decreased to 1.98 microns, an indication that the second treatment was ineffective in opening up any additional void spaces. This implies that the treatment process was not able to penetrate the biological plugging material which remained after the initial UAB ™ treatment. A further modification to the UAB™ treatment process and a more aggressive application may be required to recover any additional specific capacity. One possibility is to use acetic acid in combination with sulfamic acid, instead of hydrochloric acid, to more effectively penetrate the biomass around Well 15.

<u>Well 16:</u> During the Phase 1 study, LPC analysis revealed that Well 16 had a mean particle size of 3.39 microns. This data indicates that slightly larger particles are present around Well 16, as compared to Well 15. These LPC results therefore imply that there are larger void spaces around Well 16, suggesting that the biofouling is less severe and that there is less restriction to flow. However, prior to the first UAB™ treatment on Well 16 in August 1998, the mean particle size had been reduced to 1.28 microns. Post treatment LPC data collected in November 1998, indicates that the mean particle size had subsequently increased to 2.14 microns (Table 5). Although the treatment appeared successful, in that it restored the original specific capacity of Well 16, the LPC results suggest that the aquifer is still plugged further from the well. A preventative maintenance (PM) program will need to implemented immediately to maintain the well's specific capacity and to ensure that further biological plugging does not occur.

Laser Particle Counter Analysis	Well 15					Well 16		
	Initial UAB™ Treatment			2nd UAB™ Treatment		Initial UAB™ Treatment		
	Pre-Treatment	Post Treatment		Pre-Treatment	Post Treatment	Pre-Treatment		Post Treatment
	Oct. 6, 1997	Oct. 10, 1997	Apr. 6, 1998	Aug. 10, 1998	Nov. 2, 1998	Apr. 9, 1998	Aug. 11, 1998	Nov. 3, 1998
Mean Particle Size (in microns): (120 min. sample)	2.8	5.2	2.8	2.2	2	3.4	1.3	2.1
Per cent greater than 8 microns (by volume): (120 min. sample)	19.4%	38.3%	60.0%	0.0%	21.6%	62.5%	0.0%	18.2%

TABLE 5 Laser Particle Counter Analysis Results

3.6 Preventative Maintenance

A preventative maintenance (PM) program for both Wells 15 and 16 is essential to maintain their respective specific capacities. In November 1998, the City of North Battleford conducted PM procedures on these wells after post treatment water samples were collected by DBI for biological and chemical analysis. These PM procedures involved placing a solution of about 11 kilograms of calcium hypochlorite (HTH) into each well, and then surging the wells with their in-situ submersible pumps. Specific capacity measurements taken after the PM was applied, indicated a slight increase or stabilization of the specific capacity at both Wells 15 and 16 (see Figures 1&2). Presently, alternate PM procedures are being developed and tested in the laboratory by DBI, and will be introduced as part of the Phase 3 post monitoring program. Also, as part of preventative maintenance, ongoing detailed records should be kept on each well. Any loss in specific capacity or decreased days of delay (dd) using the BART™ system should be noted and acted upon in a timely fashion, using appropriate PM procedures.

4.0 CONCLUSIONS

1. The modified UAB™ well treatments proved to be successful in increasing the specific capacity from 2.67 to 2.99 igpm/ft at Well 15 and from 13.1 to 21.1 igpm/ft at Well 16.

2. At Well 15, the specific capacity declined sharply shortly after treatment, which suggests that the biofouling around the well is fairly extensive and the treatment was not able to effectively remove the plugging material beyond the immediate radius of the well.

3. At Well 16, the original specific capacity was restored, which validates the laboratory findings by DBI that suggest that the original specific capacity of a well can be restored if the specific capacity has declined in the order of 40 per cent.

4. After treatment, there was a slight decrease in several water chemistry parameters at each well site, which may be due to the fact that the treatment process removed some minerals that may have been concentrated in the biofilm surrounding the wells. However, there was no significant change in the overall water quality at Wells 15 and 16.

5. Post treatment biological testing indicated that high aggressivity levels of most of the nuisance-type bacteria still persisted around both Wells 15 and 16. Therefore, although the wells had some improvement in specific capacity, the biological activity had not decreased and preventative maintenance procedures are necessary to maintain the specific capacities.

6. Laser particle counting results appear to substantiate the biological findings that suggest that the treatment did not remove the biological plugging material beyond the immediate radius of each well. At Well 15, the mean particle size decreased further after treatment from 2.17 to 1.98 microns, an indication that the second treatment was ineffective in opening up any additional void spaces. At Well 16, the mean particle size increased after treatment from 1.28 to 2.14 microns. However, the initial LPC reading in April 1998 was 3.39 microns. Therefore, although the treatment restored the original specific capacity of Well 16, these results suggest that the aquifer is still plugged further from the well.

7. Specific capacity measurements taken at Wells 15 and 16 after preventative maintenance procedures were applied by the City of North Battleford in November 1998, indicate a slight increase or stabilization of the specific capacity.

8. The UAB™ treatment was not completely effective in completely removing the biological plugging material around Wells 15 and 16. Therefore, further modifications and a more rigorous application may be required to improve the effectiveness of the treatment process.

5.0 RECOMMENDATIONS

1. A preventative maintenance program is essential after treatment to maintain the specific capacities of Wells 15 and 16, and to reduce the risk of further biological plugging. Therefore, it is recommended that pump tests be conducted on both Wells 15 and 16, every three months, to collect water samples for biological testing and to calculate the specific capacity of each well. Detailed records should be kept on the testing results and on any preventative maintenance procedures that are applied.

2. It is recommended that the preventative maintenance procedures, being developed and tested in the laboratory by DBI, be evaluated and field tested on Wells 15 and 16 during the Phase 3 of this project, as required. On-site training for the City of North Battleford well maintenance staff is also recommended, to ensure any new preventative maintenance procedures are properly applied.

3. It is recommended the further laboratory experimentation and testing be conducted on the aquifer core samples to determine if other chemicals, such as acetic acid in combination with sulfamic acid, are more effective in the removal of biological plugging material. This may lead to further improvements to the UAB™ treatment process.

4. If any further well treatments are required, it is recommended that UAB™ treatment process be applied and its effectiveness evaluated.

6.0 REFERENCES

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