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EXECUTIVE SUMMARY

The Phase 3 post treatment monitoring program commenced on January 18, 1999 and was completed on November 29, 1999. The purpose of this monitoring phase was to evaluate the effectiveness of the Ultra-Acid Base™ (UAB™) well treatments applied to Wells 15 and 16, in August 1998. Although Well 17 had not experienced a decline in specific capacity and had not received a prior well treatment, it was also included in this monitor program since it is a crucial production well for the City of North Battleford. Pump tests were periodically conducted to measure the specific capacity of these wells and to collect water samples for microbiological analysis. The specific capacity measurements and the microbiological analysis data gathered during these pump tests were used to provide guidance on appropriate times for preventative maintenance procedures or requirements for future well treatments. As part of this Phase 3 study, preventative maintenance (PM) procedures, developed by DBI, were also jointly field tested and evaluated by DBI and PFRA on Wells 15, 16 and 17, as became necessary.

In July 1999, during a pump test on Well 15, sand was observed in the discharge water and further testing on this well was suspended until this problem could be rectified. Also, during the course of this Phase 3 study, it became apparent that additional well treatments would be required, and therefore, an agreement was reached between the City of North Battleford, DBI and PFRA to apply an initial UAB™ treatment on Well 17 and a second UAB™ treatment on Well 16. The UAB™ treatment process had been slightly modified since the Phase 2 well treatments in August 1998, to reflect the results of laboratory experimentation conducted jointly by PFRA and DBI. This modified UAB™ well treatment was applied to Well 16 on July 19-20, 1999, and the specific capacity improved from 11.8 to 18.9 igpm/ft. A similar well treatment was also applied to Well 17 on July 21-22, 1999, and the specific capacity improved from 14.8 to 19.6 igpm/ft. The original specific capacity of both these wells was 20 igpm/ft.

The specific capacity and microbiological activity in Wells 16 and 17 were periodically monitored to evaluate the effectiveness of the UAB™ well treatments and a subsequent PM procedure applied in October 1999. By November 29, 1999, Well 16 had a slight reduction in specific capacity, to 18.1 igpm/ft, while in Well 17 the specific capacity improved to 24.2 igpm/ft. However, the microbiological activity in both wells had generally returned to, or near, pre-treatment levels. The microbiological data suggests that although the aggressivity of some bacteria types have been reduced, the well treatments and PM procedures have not been able to suppress the regrowth of most of the nuisance bacteria. This implies that although additional pathways have been opened up by the redevelopment of the wells and the removal of some of the biological plugging material, the microbiological activity has not decreased and therefore, there is still potential for further biological plugging of the aquifer. Ongoing monitoring is required to observe any losses in specific capacity or increase in microbiological activity and to signal when appropriate PM procedures or well treatments are required, in order to control further biological plugging of the aquifer. These tests should be conducted at least every three months, with the frequency adjusted to reflect the condition observed in each well.

Based on the results of this Phase 3 study, it is recommended that PM procedures be applied when the specific capacity of a well has declined about 10-15% from original, or when the biological activity has increased by one order of magnitude. Also, any additional well treatments should be conducted before the specific capacity has declined more than 40% or when the biological activity has increased by two orders of magnitude.

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Project Partners:

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1.0 BACKGROUND

The City of North Battleford Well Rehabilitation Project is divided into three phases: a diagnostics phase, a well treatment evaluation phase and a post treatment monitoring phase. The findings from the Phase 1 diagnostics program are provided in the report, *City of North Battleford Well Rehabilitation Project, Phase 1: Well Diagnostics Program (PFRA and DBI, June 1999),* and the results of the Phase 2 well treatment evaluations are provided in the report, *City of North Battleford Well Rehabilitation Project, Phase 2: Well Treatment Evaluation (PFRA and DBI, December 1999).* Upon completion of the Phase 2 post treatment diagnostic testing in November 1998, the Phase 3 post treatment monitoring phase was initiated to evaluate the effectiveness of the Phase 2 well treatments. The project area is shown in Figure 1.

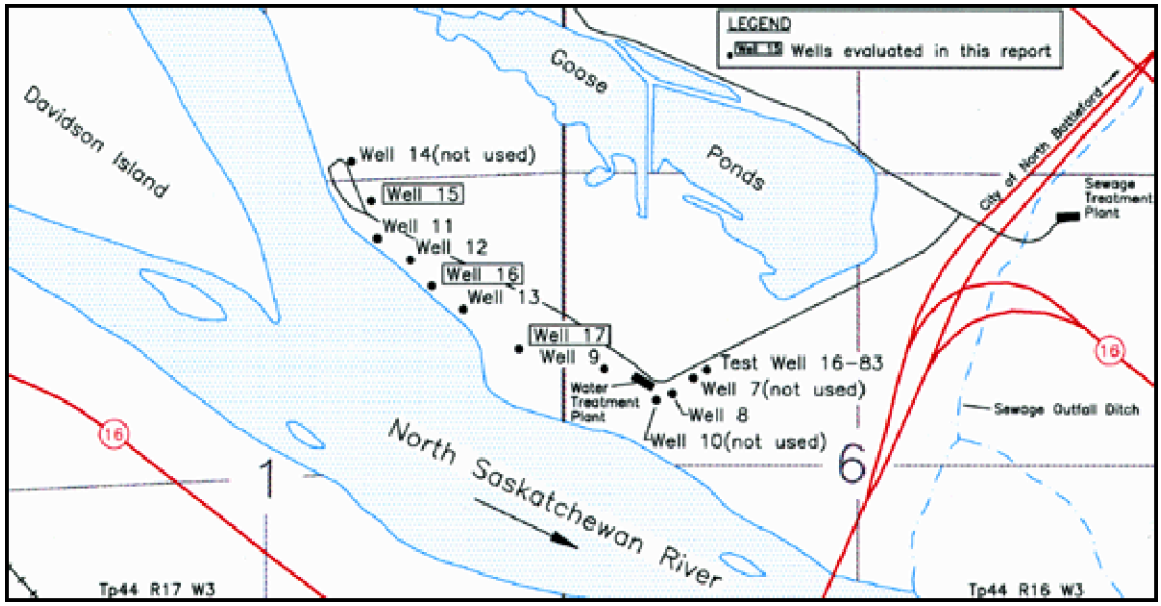

FIGURE 1 City of North Battleford Well Field

1.1 Introduction

The Phase 3 post treatment monitoring program was initiated on January 18, 1999, and was completed on November 29, 1999. The purpose of this monitoring phase was to evaluate the effectiveness of the well treatments in removing the biological plugging material associated with the biofouling of Wells 15 and 16. Pump tests were periodically conducted throughout the year to measure the specific capacity of the wells and to collect water samples for microbiological analysis. Also, as part of this Phase 3 work, preventative maintenance (PM) procedures developed by DBI, were jointly field tested and evaluated by DBI and PFRA on Wells 15, 16 and 17, as required. During the course of this monitoring program, it also became apparent that additional well treatments would be required, and therefore, an agreement was reached between the City of North Battleford, DBI and PFRA to apply an initial UAB^{TM} treatment on Well 17 and a second UAB^{TM} treatment on Well 16. These well treatments were conducted from July 19-23, 1999, with a UAB^{TM} treatment that has been slightly modified since the Phase 2 field tests and evaluations in August 1998. The Phase 3 post treatment monitoring and the subsequent well treatment results are provided in this report.

2.0 MATERIAL AND METHODS

2.1 Pump Testing Procedures

Two-hour pump tests were periodically conducted on Wells 15, 16 and 17 throughout 1999, to determine their specific capacity and to collect water samples for microbiological analysis. This data was then used to provide guidance on appropriate times for preventative maintenance procedures or future well treatments. 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. Prior to conducting these pump tests, the wells are taken out of service for a minimum of eight hours. The purpose of this 8-hour shutdown is to allow loosely attached bacteria to be detached when the pump is turned back on, thereby providing a more accurate representation of the types of bacteria present and their level of aggressivity for the microbiological analysis.

2.2 Microbiological Testing Procedures

The microbiological testing involved collecting water samples from the wells during a 2-hour pump test, at 1, 3, 5, 10, 20, 30, 60, 90 and 120 minutes. An analysis for biological activity was then conducted 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™ (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). The water samples were placed into the BART™ biodetectors on the sample collection date and were then examined once a day for ten consecutive days, with any observed reactions recorded.

The BART™ system offers a simple method to detect the presence and aggressivity of nuisance bacteria that are often involved in the water well biofouling. Two forms of data are obtained by using this system: 1) the days of delay (DD) 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 are used to determine the level 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). A summary of the data supplied by DBI, to determine the aggressivity levels of bacteria, is provided in Table 1.

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

Legend: High - greater than 10,000 colony-forming units per millilitre (cfu/ml)
Medium - 100 to 10,000 cfu/ml
Low - less than 100 cfu/ml

TABLE 1 Bacterial Agressivity Levels

2.3 Preventative Maintenance Procedures

As part of the Phase 3 study, preventative maintenance (PM) procedures were developed by DBI, and some of these procedures were subsequently field tested and evaluated jointly by DBI and PFRA on the wells, as required. The various PM procedures were developed by modifying current and well-established water well maintenance practices, and by building on the knowledge gained in the development of the UAB^{TM} treatment process.

The PM procedures developed by DBI are described as either passive or active. Passive PM is a procedure where sufficient chemical is introduced into the well to kill and traumatize the bacteria, such as in a standard shock chlorination procedure. However, if the biological plugging problem is severe, even increased chemical contact time may prove ineffective at removing the plugging material from the aquifer around the well screen. By contrast, active PM includes air surging, mechanical surging or jetting to assist the PM chemicals in penetrating more restrictive areas of the aquifer around the well screen, and this agitation also helps to dislodge the biological plugging material and move it into the well where it can be removed by pumping. The PM procedures developed by DBI during the course of the Phase 3 study are included in Appendix B.

2.4 UAB^{TM} Treatment Process

The Ultra-Acid Base (UAB^{TM}) treatment process has been modified to reflect the results of laboratory experimentation conducted jointly by PFRA and DBI. This modified treatment process was field tested and evaluated by DBI and PFRA on Wells 16 and 17 from July 19-23, 1999, and consists of three distinct phases.

The ***first phase*** involves preheating the area around the well screen. This step also 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 4000-litre hot water solution, with CB-4 wetting agent (0.75% by volume), is heated to about 85^{o}C and added to each well. A specially designed surge block tool is then placed into the well screen and the entire screen interval is air-developed and surged in one-metre increments from the bottom to the top of the screen. This development procedure moves the chemical solution into the surrounding sand pack and aquifer material, and allows the CB-4 wetting agent 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 one hour in duration, during which time no water is discharged from the well. After this, air-lift pumping is conducted in one-metre increments from the top to the bottom of the screen to remove the material dislodged during the development period. (Prior to initiating this first phase, a wire brush may also be lowered into the well screen to help clean out the screen slots prior to preheating the well screen area, as required.)

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 9.5 to 2.5, 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 sodium hypochlorite (5% by volume) to obtain a pH of 9.5, and then using acetic acid (10% by volume) to obtain a pH of 2.5. Sulfamic acid is also added to the acetic acid solution, as required, to maintain a pH of 2.5. Both steps involve using CB-4 (1% by volume) and a hot water solution of 2000 litres and 4100 litres, respectively. The development and air-lift pumping procedure is similar to that conducted during the first phase of

treatment. For the acid step, an overnight contact time is required to dissolve iron and manganese oxides that have collected in the biofilms and encrustations before conducting air-lift pumping and surging to clean out the well.

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

Two-hour pump tests were conducted on Wells 15, 16 and 17, as part of the Phase 3 monitoring program. Pump tests were also conducted before and after a well treatment or preventative maintenance (PM) procedure was applied. These pump tests were jointly conducted by DBI and PFRA, between January and December 1999, to measure the specific capacity of the wells and to collect water samples for microbiological analysis. The specific capacity measurements calculated for each well during these pump tests are provided in Table 2, with the detailed pump test results included in Appendix A. The specific capacity measurements are presented as imperial gallons per minute per foot of drawdown (igpm/ft).

Date (1999)	Well 15		Well 16		Well 17	
	S.C. (igpm/ft)	Comments	S.C. (igpm/ft)	Comments	S.C. (igpm/ft)	Comments
Jan. 18-20	2.83	post 2nd UAB™ treatment	18.82	post 1st UAB™ treatment	19.36	regular monitoring
Apr. 14	2.47	pre Passive PM	14.75	pre Passive PM	-	no testing
July 5	2.61	sand entering well;	11.80	post Passive PM	13.6	pre Passive PM
July 19	-	no further testing of well	-	no testing	14.8	post Passive PM
July 20-21	-		19.0	post 2nd UAB™ treatment	18.4	post 1st UAB™ treatment
Aug. 3-4	-		18.9	post treatment (step test)	19.6	post treatment (step test)
Sept. 28	-		16.1	post treatment	20.2	post treatment
Oct. 19	-		16.8	pre Active PM	20.5	pre Active PM
Oct. 20	-		18.7	post Active PM	23.0	post Active PM
Nov. 29	-		18.1	post Active PM	24.2	post Active PM

TABLE 2 Specific Capacity Measurements: January to November 1999

3.1.1 Well 15

Since the second UAB™ well treatment in August 1998, the specific capacity of Well 15 appears to have stabilized at about 2.5 igpm/ft, as shown in Figure 2. On January 22, 1999, the specific capacity was measured at 2.83 igpm/ft and by April 14, 1999, the specific capacity had declined slightly to 2.47 igpm/ft. A passive PM was conducted by personnel from the City of North Battleford following the April 14th pump test, as outlined in Appendix A. On July 5, 1999, the specific capacity was measured at 2.61 igpm/ft. However, during this pump test, an excessive amount of sand was observed in the discharge water. A down hole camera was subsequently lowered into the well and it was discovered that a small separation appears to exist between two well screen sections. Therefore, no further monitoring or preventative maintenance (PM) will be applied to Well 15 until this situation is rectified.

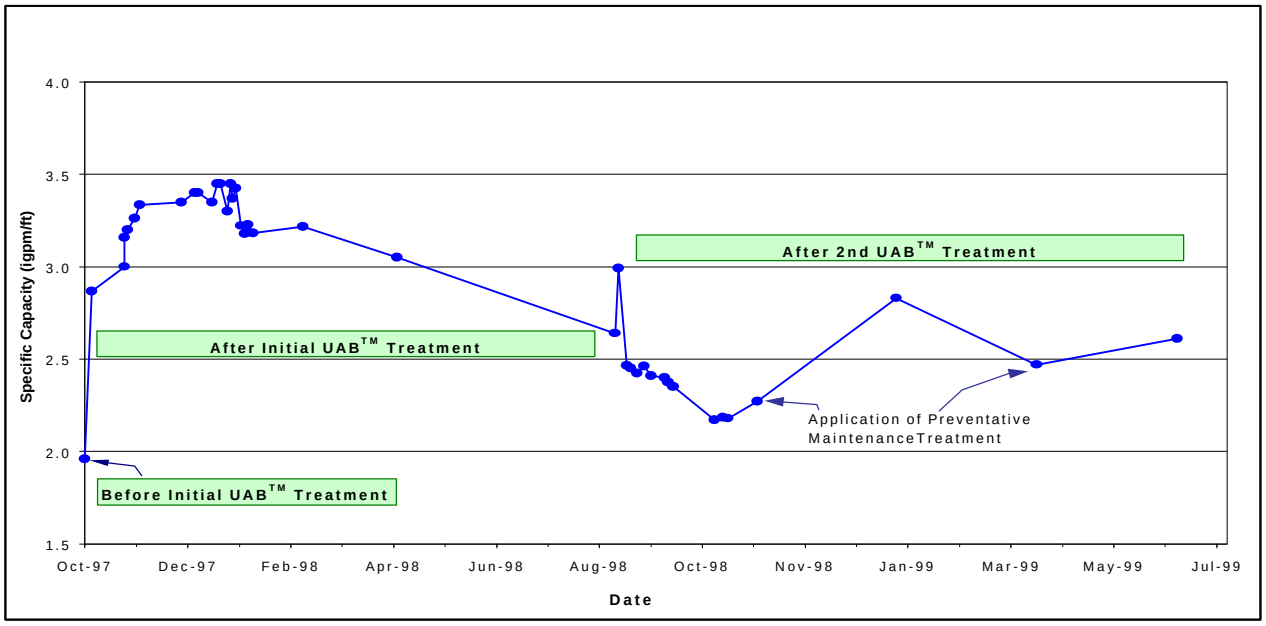

FIGURE 2 Well 15: Specific Capacity Measurements 1997-1999

3.1.2 Well 16

After the initial UAB™ well treatment in August 1998, the specific capacity of Well 16 remained fairly stable, at 19.2 igpm/ft, as shown in Figure 3. On January 18, 1999, a slight reduction was

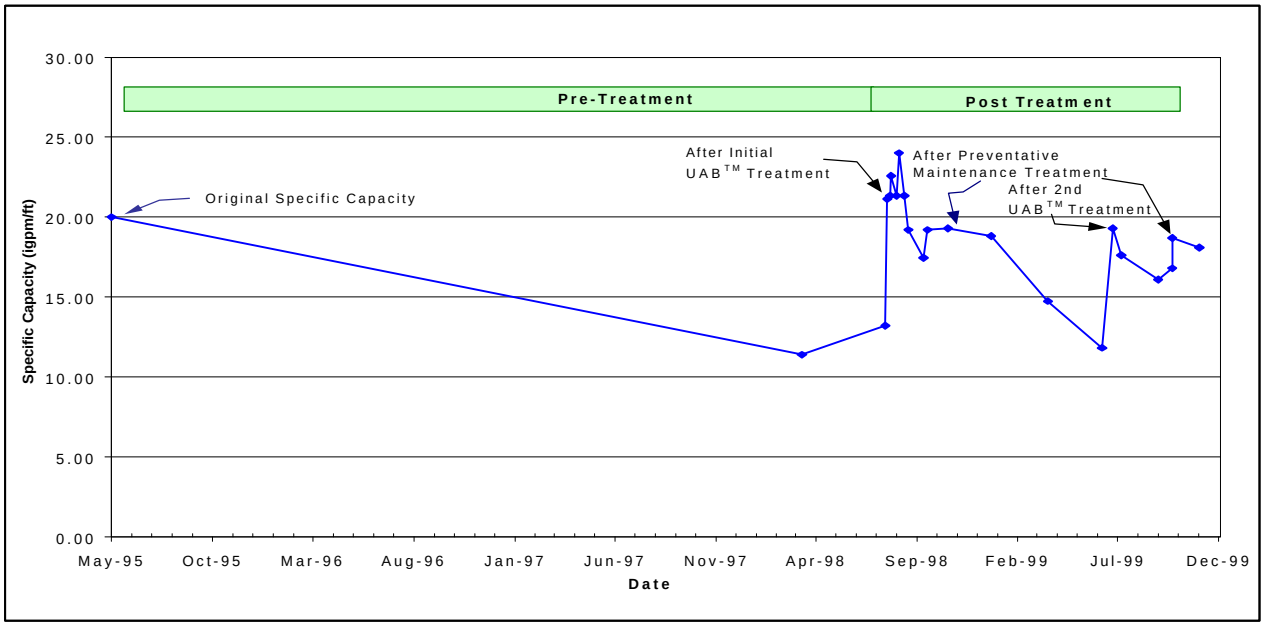

FIGURE 3 Well 16: Specific Capacity Measurements 1995-1999

observed, with a specific capacity measurement of 18.82 igpm/ft. However, by April 14, 1999, the specific capacity had dropped significantly, to 14.75 igpm/ft. A passive PM procedure was immediately conducted by personnel from the City of North Battleford following the April 14th

pump test, as outlined in Appendix A. On July 5, 1999, the specific capacity was measured at 11.82 igpm/ft, which was about a 40% decline from original. The PM procedure had not been successful in maintaining the specific capacity of Well 16 at post treatment levels, and therefore, a second UAB™ well treatment was applied on July 19-20, 1999. After the UAB™ treatment, the specific capacity improved to 18.9 igpm/ft, as measured from a step drawdown test performed on August 3, 1999. However, by October 1999, the specific capacity had again declined to about 16.8 igpm/ft. At this time, an active PM was applied to prevent a further decline in specific capacity, as outlined in Appendix A. After the active PM procedure, the specific capacity improved to 18.7 igpm/ft. However, by the end of November 1999, the specific capacity had declined slightly to about 18 igpm/ft. Ongoing monitoring of this well is recommended and preventative maintenance procedures may have to be applied again shortly if the specific capacity continues to decline.

3.1.3 Well 17

On January 18, 1999, the specific capacity of Well 17 was measured at 19.36 igpm/ft, a slight decrease from the original specific capacity of 20 igpm/ft. Well 17 was not tested in April 1999, and on July 5, 1999 the specific capacity was measured at 13.6 igpm/ft, a decline of about 32% from original, as shown in Figure 4. Therefore, a UAB™ well treatment was applied on July 21-22, 1999. A subsequent step drawdown test conducted on August 4, 1999, indicated that the specific capacity had improved to 19.6 igpm/ft. Over the next few months, the specific capacity was found to gradually improve and after an active PM was performed on October 19, 1999, the specific capacity was measured at 23.0 igpm/ft. On November 29, 1999, the specific capacity was found to have further improved to 24.2 igpm/ft. Although the specific capacity is now actually about 20% above the original specific capacity, ongoing monitoring is still recommended to observe any changes over time.

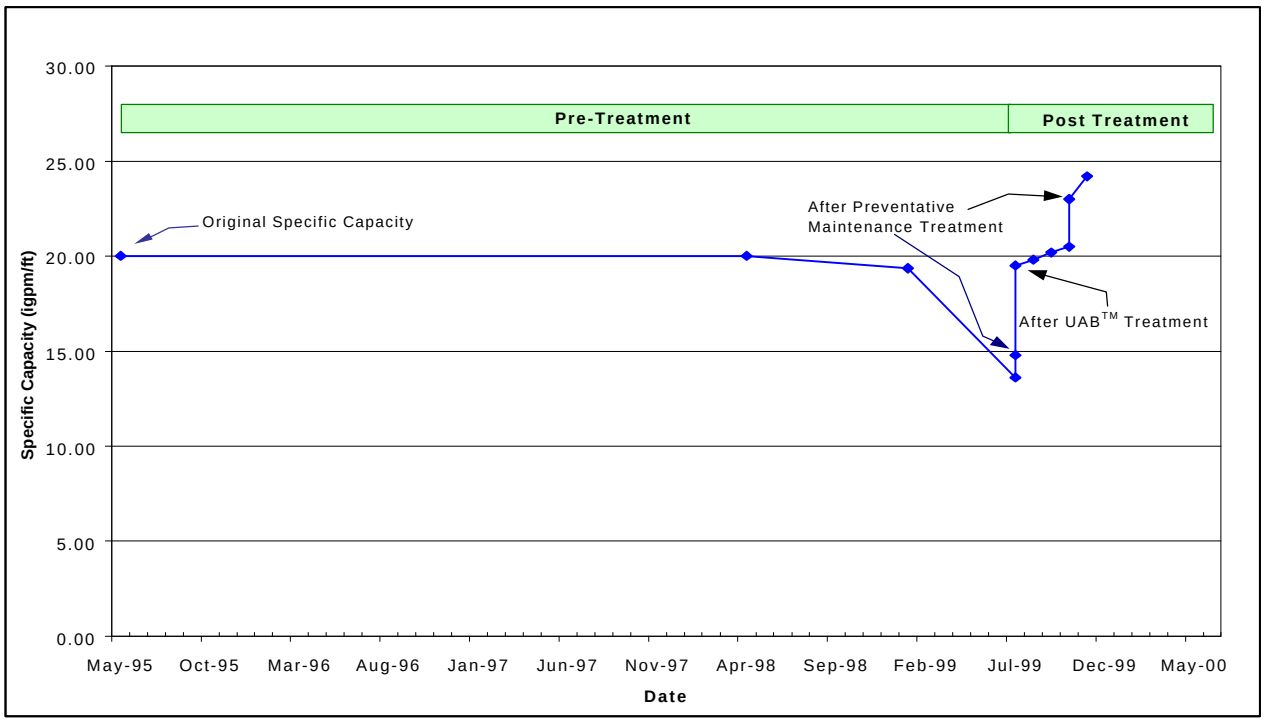

FIGURE 4 Well 17: Specific Capacity Measurements 1995-1999

3.2 Microbiological Testing

The microbiological testing involved collecting water samples at 1, 3, 5, 10, 20, 30, 60, 90 and 120 minutes during the 2-hour pump tests conducted on the wells. 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 C.

3.2.1 Well 15

The BART™ results, as shown in Table 3, indicate that the aggressivity of the bacteria causing the biofouling problems around Well 15 have remained fairly high and preventative maintenance is required to prevent a further increase in microbiological activity. However, in July 1999, a problem with sand entering the well halted further testing on Well 15. No further well treatments or PM procedures are recommended until this problem is rectified.

BART™	Well 15		Well 16		Well 17
	January 20, 1999 After 2nd UAB™ Treatment	April 14, 1999 Prior to PM Procedures	January 18, 1999 After Initial UAB™ Treatment	April 14, 1999 Prior to PM Procedures	January 19, 1999 Ongoing Monitoring
HAB	low	medium	medium	medium	medium
IRB	high	high	high	high	high
SRB	high	medium	high	high	high
SLYM	high	high	high	low	high
DN	medium	high	medium	low	low

TABLE 3 BART™ Results (after 120 minutes of pumping): January and April 1999

3.2.2 Well 16

During the Phase 3 monitoring period, results from the BART™ analyses indicate that the IRB, SRB and SLYM bacteria have a generally high aggressivity level and the HAB and DN bacteria have a medium aggressivity level, as shown in Tables 3 and 4. A review of the detailed data included in Appendix C, indicates that, based on the time to an initial reaction (days of delay), the IRB, and SLYM bacteria increased in aggressivity from January 1999 to July 1999 by one order of magnitude. A UAB™ treatment was then applied in July 1999, and on September 28, 1999, the aggressivity of both the IRB and SLYM bacteria had decreased one order of magnitude. However, by October 19, 1999, the aggressivity of these bacteria again increased and active PM was applied, as outlined in Appendix A. By November 29, 1999, based on a comparison to the October 1999 results, the aggressivity of the IRB and SLYM bacteria had again decreased one order of magnitude. This data suggests that although the regrowth of these bacteria occurs fairly quickly, both the well treatment and the active PM procedure appear to be able to reduce their aggressivity levels. The aggressivity levels of the HAB and DN bacteria also increased from January 1999 to July 1999. After the UAB™ treatment the HAB and DN bacteria were reduced by one order of magnitude and have remained fairly stable to November 29, 1999. The SRB data collected during the Phase 3 study indicates that, based on the 120-minute sample, the agressivity level of the SRB actually increased after treatment, but again decreased in aggressivity by November 1999.

BART™	Well 16				Well 17			
	July 5/99 Post Passive PM Prior to 2nd UAB™ Treatment	Sept.28/99 Post 2nd UAB™ Treatment	Oct.19/99 Pre Active PM	Nov.29/99 Post Active PM	July 5/99 Post Passive PM Prior to 2nd UAB™ Treatment	Sept.28/99 Post 2nd UAB™ Treatment	Oct.19/99 Pre Active PM	Nov.29/99 Post Active PM
HAB	high	medium	medium	medium	medium	medium	medium	medium
IRB	high	high	high	high	high	high	high	high
SRB	high	high	low	medium	high	high	high	high
SLYM	high	high	high	high	high	high	high	high
DN	medium	high	medium	medium	high	low	medium	medium

TABLE 4 BART™ Results (after 120 minutes of pumping): July to November 1999

3.2.3 Well 17

During the Phase 3 monitoring period, results from the BART™ analyses indicate that the IRB, SRB and SLYM bacteria have a generally high aggressivity level and the HAB and DN bacteria have a medium aggressivity level, as shown in Tables 3 and 4. A review of the detailed data included in Appendix C, indicates that, based on the time to an initial reaction (days of delay), the aggressivity levels for most of the bacteria increased one to two orders of magnitude from January 1999 to July 1999. Also, despite the initial well treatment in July 1999 and the subsequent active PM conducted in October 1999, the aggressivity levels have remained substantially the same to November 1999, except for the DN bacteria which have seen an order of magnitude decrease in aggressivity levels. This data suggests that the microbiological activity has increased significantly from January 1999 to July 1999, and well treatments and PM procedures have had limited success in reducing the aggressivity levels of the nuisance bacteria around Well 17.

4.0 DISCUSSION OF FINDINGS

The results of the Phase 3 monitoring program emphasize the necessity of establishing and maintaining regular monitoring procedures, in order to reduce the risk of a deterioration in well yield. This is particularly evident in Well 17, where only a minimal decline in specific capacity was initially observed in January 1999, but by July 1999, a 32% decrease was recorded. Fortunately, the UAB™ treatment and the subsequent active PM procedure restored the original capacity of Well 17, and the specific capacity has actually increased to 20% above original. This increase in specific capacity, above original, may be due to the increased well development that occurred during the well treatment and active PM procedure. Although the specific capacity has improved, the microbiological data suggests that the well treatment and PM procedure have not reduced the aggressivity levels of the nuisance bacteria around the well. This implies that although additional pathways have been opened up by the removal of some of the biological plugging material and the redevelopment of the well, the microbiological activity has not decreased, and therefore, there is still potential for further biological plugging of the aquifer. Any losses in specific capacity or decrease in time lag using the BART™ system must be recorded and appropriate PM procedures applied to minimize biological plugging of the aquifer.

The importance of applying an initial well treatment before a well has had a substantial reduction in specific capacity is evidenced by the results from Well 16. By 1998, Well 16 had experienced a decline of about 43% from its original specific capacity and the initial UAB™ well treatment in August 1998 was only able to recover the specific capacity to within 10% of original. Within a year, Well 16 had again declined to 41% of original specific capacity, and a second well treatment in July 1999 and an active PM procedure in October 1999 were necessary to restore the specific capacity to within 10% of original. These findings substantiate the laboratory research conducted by DBI during the Phase 1 and 2 studies of this project, which suggest that once a well has had a reduction in specific capacity of greater than 40% due to biological plugging, the ability to recover the lost specific capacity to original levels is extremely difficult. Also, the PM procedures conducted on Well 16 suggest that PM should be conducted once a well has experienced a decline of 10-15% in specific capacity. An increase in microbiological activity is also a signal that PM procedures should be implemented. Based on the results obtained from Well 16, it is recommended that pump tests and sampling for microbiological activity be conducted at least every three months.

As part of this Phase 3 study, UAB™ treatments were field tested and evaluated on Wells 16 and 17. The treatment process was modified slightly from the Phase 2 study, as described in section 2.3 of this report, with acetic acid replacing muriatic acid in the acid stage of the treatment. Acetic acid was chosen since it has the ability to traumatize biofilms more effectively than most of the commonly-used acids for well treatments (Schnieders, 1996). However, acetic acid is poor at removing carbonate and sulphate scale, and therefore, sulfamic acid is added to the acetic acid to assist in removing 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. Based on observations to the end of November 1999, the current well treatments have been relatively successful. Well 16 was reported to have a specific capacity of about 10% below original, while Well 17 was reported to have a reported specific capacity of about 20% above original. Further monitoring is necessary to evaluate the long-term effectiveness of these well treatments.

5.0 CONCLUSIONS

1. The regular pump testing and microbiological testing conducted during this Phase 3 study was useful in indicating when well treatments or preventative maintenance procedures were required.

2. The active PM procedure conducted in October 1999 on Wells 16 and 17 has shown promise in maintaining the specific capacity of these wells. However, PM procedures should be applied when the specific capacity of a well has declined about 10-15% from original, and the biological activity has not increased by more than one order of magnitude.

3. The results of the Phase 3 findings and previous laboratory research by DBI suggest that once a well has had a reduction in specific capacity of greater than 40% due to biological plugging, the ability to recover the lost specific capacity to original levels is extremely difficult.

4. Based on observations to the end of November 1999, the UAB^{TM} well treatments conducted on Wells 16 and 17 in July 1999 have been relatively successful. Well 16 has a reported specific capacity of about 10% below original, while Well 17 has a reported specific capacity of about 20% above original.

5. During the pump testing of Well 15 in July 1999, sand was entering the well, and therefore, no further PM procedures or well treatments could be performed on this well until the problem is rectified.

6. The regrowth of the nuisance bacteria around Well 16 occurs fairly quickly. However, both the UAB^{TM} well treatment and the PM procedure were able to reduce the aggressivity levels of these nuisance bacteria. In Well 17, this was not as evident, where only the SRB appear to have experienced reduced levels of aggressivity.

6.0 RECOMMENDATIONS

1. It is recommended that a regular monitoring program be implemented 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 active PM procedures 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.

3. It is recommended that a well treatment be conducted before the specific capacity has declined more than 40% or the biological activity has increased by two orders of magnitude.

4. It is recommended that the City of North Battleford rectify the sand pumping problem observed in Well 15 by hiring an experienced water well driller to investigate this situation and determine if a viable solution is available. Once the sand pumping problem is rectified, active PM procedures can be applied to this well to maintain its specific capacity.

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