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Canada

SUSTAINABLE WATER WELL INITIATIVE (SWWI)

RURAL MUNICIPALITY OF MOUNT HOPE # 279

WATER WELL INVENTORY AND MICROBIOLOGICAL ACTIVITY ASSESSMENT

Prepared by:
PFRA-Earth Sciences Unit
Agriculture and Agri-Food Canada
1800 Hamilton Street
Regina, Saskatchewan
S4P 4L2

Unit Manager:
John Lebedin
ph: (306) 780-5207; fax: (306) 780-5018
email: lebedinj@em.agr.ca

Report Authors:
Daryl Jaques
ph: (306) 780-6554
email: jaquesd@em.agr.ca

Harry Rohde
ph: (306) 780-8142
email: rohdeh@em.agr.ca

Information on other SWWI projects available from: http://www.agr.ca/pfra/water/swwie.htm

EXECUTIVE SUMMARY

Water wells are the primary water supply source for most rural residents on the Canadian Prairies, and developing methods to safeguard and sustain water well environments is fundamental in maintaining and improving the quality of life for the rural sector. In this regard, the Prairie Farm Rehabilitation Administration (PFRA) created the Sustainable Water Well Initiative (SWWI) to address concerns of declining well yield and water quality deterioration. As part of the SWWI, several studies have been initiated across the Prairies to better understand the cause of groundwater supply problems. This current study was undertaken by the PFRA, in cooperation with the Rural Municipality (R.M.) of Mount Hope, to identify the extent and type of water supply problems within the R.M. and to evaluate the potential role of groundwater microorganisms in the deterioration of water well supplies. Strategic funding and support for this study has been provided by the Canada-Saskatchewan Agri-Food Innovation Fund (AFIF).

This study consisted of two data collection components. First, a water well inventory was conducted, which consisted of contacting rural homeowners by telephone to gather general water well information. Secondly, microbiological testing was performed on randomly-selected wells within the R.M. of Mount Hope to establish the rate and degree of bacterial activity in these wells. This data was then compiled and analyzed by PFRA-Earth Sciences staff, and the study results are provided in this report.

The water well inventory identified 193 water wells within the R.M. of Mount Hope, and information was collected on 183 of these wells through responses obtained from the telephone questionnaire. Of these 183 wells, 131 wells were active and 52 wells were either abandoned, inactive or stand-by. The questionnaire results revealed that the vast majority of the respondents were generally satisfied with their well yield and water quality appeared to be the main concern. The main water quality problem identified in the telephone questionnaire was iron, with over half of the wells reported to have high iron concentrations. The presence of iron often causes water discolouration (i.e. slightly red or yellow), staining of plumbing fixtures and iron deposition in the water distribution system. Another indication that the overall water quality in the study area may be poor is that less than half of the wells were reported to be used as a drinking water source.

Limited data is available on the wells reported by well owners as abandoned, inactive or stand-by. Most of these wells were reported to be abandoned or inactive due to well yield, well corrosion, structural problems or sand pumping problems. Therefore, although water quality has been identified as the main concern in the R.M., it appears that a water quality problem is generally tolerated or treated rather than abandoning the water well supply.

The microbiological testing, using the Biological Activity Reaction Test (BART™) system, revealed that almost 80 percent of the sampled wells contained at least one type of highly aggressive bacteria, with iron related bacteria (IRB) being the most prominent nuisance bacteria in the study area. This implies that most of the sampled wells are at some stage of biofouling. The study results also showed that the presence of highly aggressive levels of nuisance bacteria may not always be reflected in reduced well yields or a deterioration in water quality. Therefore, it is important that biofouling of a well not be ignored and regular maintenance/treatment procedures be implemented if biofouling is suspected.

Nitrate testing was conducted in conjunction with the microbiological testing, since nitrate contamination is often a common problem experienced in an agricultural setting. An attempt was also made to determine if a relationship existed between the presence of nitrates in the groundwater and high bacteriological activity. In comparing the microbiological test results to the nitrate analysis results, it was found that 60 per cent of the wells with high aggressivity levels, for all the three types of bacteria tested, had nitrate levels in excess of 10 mg/L. However, it should be noted that groundwater generally contains sufficient nutrient sources to encourage the growth of these naturally-occurring nuisance bacteria.

The nitrate analysis results indicated that 40 per cent of the wells had nitrate levels of 10 mg/L or greater, and 18 per cent of the wells exceeded the provincial guideline of 45 mg/L (as NO_3). All, but one of the wells, with nitrate levels above 45 mg/L were shallow wells (<15 metres), and were generally located within silty to sandy surficial deposits. The presence of nitrates often signal that groundwater has been contaminated by human/animal waste or chemical fertilizers. Therefore, if elevated nitrate levels are encountered, the well should also be tested for the presence of coliform bacteria and any land activities/practices identified that represent potential sources of contamination. In these cases, it is also recommended that site inspections be carried out and mitigative measures implemented to reduce the nitrate levels, with periodic monitoring of nitrate levels conducted to ensure that levels are not increasing.

ACKNOWLEDGEMENTS

<u>*Rural Municipality of Mount Hope #279:*</u>
We gratefully acknowledge and appreciate the cooperation and assistance of the R.M. of Mount Hope and its residents during the course of this study.

<u>*PFRA Watrous District:*</u>
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<u>*Summer Students:*</u>
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1.0 BACKGROUND

Water wells are the primary water supply source for most rural residents on the Canadian Prairies, with approximately 400,000 water wells installed across the Prairies since 1960 (Lebedin et al, 2000). In Saskatchewan, approximately 45% of the population currently use groundwater for drinking purposes. Of this total, approximately 23% are rural residents (Vogelsang, 1997). Understanding the cause of groundwater supply problems and developing methods to sustain the reliability and environmental well-being of water well environments is fundamental in maintaining and improving the quality of life for the rural sector. Currently, when the quality or quantity of water produced declines dramatically, wells are routinely abandoned or treatments are applied with little understanding of the cause of these problems. The cost of replacing these wells can have significant economic impact on the owner. Correctly identifying the cause of water well deterioration offers the possibility of effective maintenance and treatment instead of well abandonment.

To address concerns of declining well yield and water quality deterioration, the Prairie Farm Rehabilitation Administration (PFRA) agreed to direct a series of groundwater studies in the Prairie Provinces. These studies led to the creation of the Sustainable Water Well Initiative (SWWI). The goal of this initiative is to work with rural communities, the water well industry, treatment specialists and researchers to investigate the causes of water well deterioration and to provide improved advice on methods used to diagnose, prevent and treat well problems. The SWWI has initially focused on the effects of microbiological activity (biofouling) on water wells, since the diagnosis and remediation of this problem is not as well understood as the physical and chemical aspects of water well deterioration.

Biofouling of a water well occurs when biofilms accumulate a sufficient amount of debris to interfere with water flow and change the nature of the aquifer environment immediately around the well. Installing and pumping a well increases the level of oxygen and nutrients in the well and surrounding aquifer. This encourages bacteria to colonize surfaces in and around the well intake. The bacterial colonies will form a gel-like slime or biofilm that captures minerals and other deposits such as clays and silts, that move to the well during pumping. Different types of organisms often grow together in the zone of biofouling, processing the groundwater constituents that flow into the well, as well as creating possible host environments for other non-desirable microbes to exist. Therefore, it is important to understand the biofouling process and its effect on water well infrastructure in the Prairie region.

1.1 Introduction

The Rural Municipality (R.M.) of Mount Hope #279 is located about 80 kilometres north of Regina, Saskatchewan, and encompasses Townships 26-30, Ranges 19 and 20; Townships 28-30, Range 21; and the north half of Township 25, Rge 20 W2M, as shown in Figure 1. Like many regions in Canada, locating a reliable source of groundwater can often be difficult in the R.M. of Mount Hope, and once a well is installed, problems such as declining well yield and water quality deterioration can often develop. Therefore, a study was undertaken by the PFRA, in cooperation with the R.M. of Mount Hope, to identify the extent and type of water supply problems encountered within the R.M. and to evaluate the role of groundwater microorganisms in the deterioration of water well supplies.

The two main objectives of this study were as follows:

- Inventory the state of water wells in the study area and identify the type and extent of water supply problems present.

- Determine the impacts that naturally-occurring nuisance bacteria in groundwater have on water quality, well production rates, and well life and provide recommendations to address these impacts.

This study commenced on August 14, 2000, and consisted of two data collection components. First, rural homeowners were contacted by telephone to gather basic water well information. Secondly, microbiological testing and nitrate testing was performed on water samples gathered from randomly-selected wells within the rural municipality. The water sample collection was completed on October 5, 2000. The data from these two study components was then compiled and analyzed by PFRA-Earth Sciences staff, and the results are provided in this report. Strategic support and funding for this study has been provided by the Canada-Saskatchewan Agri-Food Innovation Fund (AFIF).

At the time of this study, a companion study was conducted by the PFRA Watrous District Office to collect additional water quality data for some of the randomly-selected wells that were sampled in the study area. These water samples were then submitted to the Saskatchewan Research Council Laboratory in Saskatoon, Saskatchewan for analysis. The results from these analyses were compiled by the PFRA Watrous District Office on behalf of the R.M. of Mount Hope.

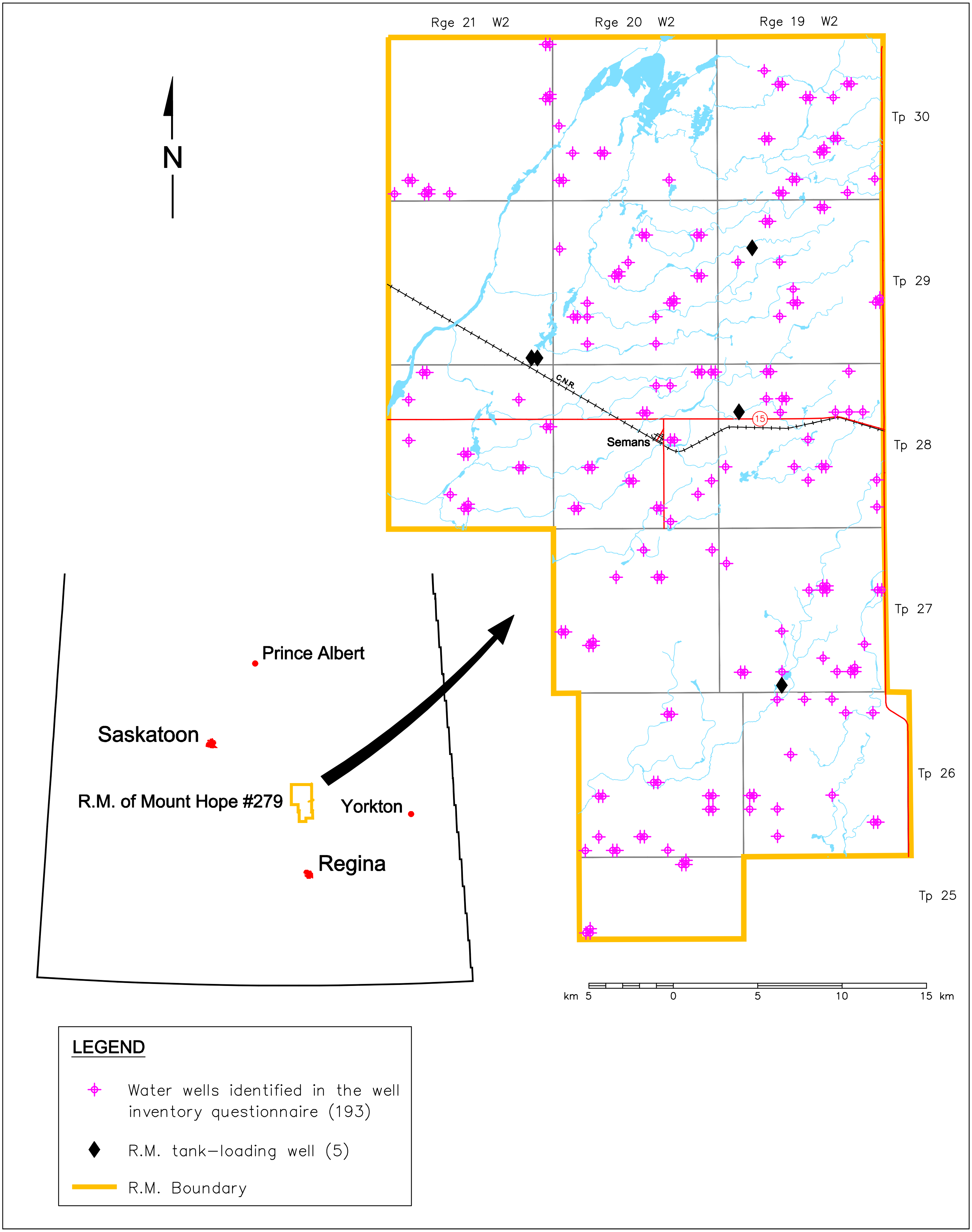


FIGURE 1 Location Plan

2.0 WATER WELL INVENTORY

2.1 Methodology

The purpose of conducting the water well inventory was to determine the state of the water wells within the R.M. of Mount Hope. In order to facilitate this process, a comprehensive questionnaire was developed by PFRA-Earth Sciences Unit to collect general water well information from well owners. At a meeting held on July 25, 2000, between PFRA personnel from the Earth Sciences Unit, the Watrous District Office and the Water Quality Unit, it was decided that the most expeditious method of conducting this inventory would be by telephone. The R.M. provided a list of current residents and the PFRA Watrous District Office established an electronic database using MS Access software. Two students were hired to contact the residents by telephone to gather basic water well data, as well as information on any water supply or water quality problems that were being experienced. The information collected was then entered into the database. The Sask Water groundwater database was also used to provide background information on water wells identified by well owners. This telephone questionnaire was conducted from August 14- 31, 2000.

2.2 Water Well Inventory Results

The responses provided by well owners, as part of the telephone questionnaire, were tabulated and analyzed by PFRA-Earth Sciences Unit. As a result of this water well inventory, 193 water wells were identified within the R.M. and information was collected on 183 of these wells. Responses were not received from 10 well owners. A summary of the basic information provided by the well owners is shown in Table 1.

Water Well Inventory: Questionnaire Data	Statistical Data		Comments
	Numbe	Per cent	
Wells with information on well	183	95%	from a total of 193; doesn't include the five RM wells
Active wells	131	72%	median age is 17 yrs.; data from 109 wells
Abandoned/Inactive/Stand-by Wells	52	28%	avg. age prior to abandonment: 18 yrs.;data from 10
Water Supply Information (reported from the 131 active wells)			
Wells with adequate yield	118	90%	
Wells used for drinking water	60	46%	
Noticeable reduction in yield	12	9%	
Water Quality Information (received reports for 129 of the 131 active wells)			
Wells with excellent or good water	62	48%	
Wells with fair or poor water	67	52%	
Noticeable decline in water quality	16	12%	
Water Treatment Information (reported from the 131 active wells)			
Wells that have been treated	50	38%	shock chlorination is the most common method
Wells with treatment equipment	31	24%	generally a water softener or iron filter equipment

TABLE 1 Water Well Questionnaire Results

2.2.1 Water Quality Concerns

A review of the questionnaire data revealed that water quality appears to be the main problem for many of the 131 active wells reported in the R.M. of Mount Hope. Over 50 per cent of the wells are reported to have fair to poor water quality (see Table 1). Although only 12 per cent of the wells have reported a noticeable deterioration in water quality, there appears to be various ongoing water quality concerns. Some of the general concerns are shown in Figure 2.

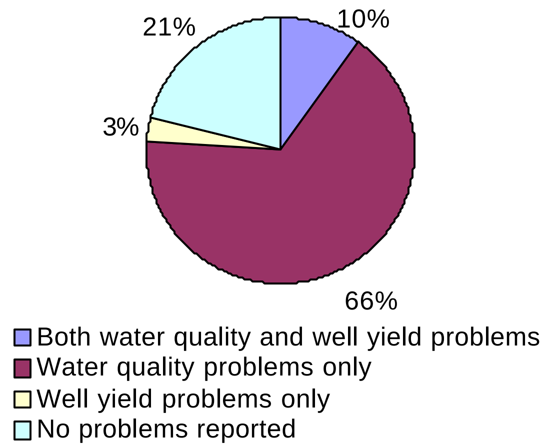


FIGURE 2 Water Well Owners Concerns

A closer review of the questionnaire responses for the 131 active wells, in regards to the water quality information, reveals that:

- **76% of the water wells,** for a total of 99, reported some sort of water quality problem. These problems include high iron, odour, colour, silt or particulates in water, gas, staining, and unpleasant taste.
- **54% of the water wells,** for a total of 71, reported high iron concentrations, and 10% of these wells, for a total of 7, reported an increase in iron.
- **42% of the water wells,** for a total of 55, reported staining of plumbing fixtures.

Although 50 percent of well owners reported fair or poor water quality and about 76 per cent reported at least one water quality problem, only 38 per cent of the wells have been treated at least once in their lifetime (see Table 1).

2.2.2 Inactive/Abandoned/Stand-by wells:

As outlined in Table 1, 28 per cent of the water wells, for a total of 52, were reported to be inactive, abandoned or stand-by. Of these 26 were inactive, 25 were abandoned or sealed and one had a pump in place and was serving as a stand-by well. However, detailed data is limited, and only 35 questionnaire respondents reported a reason for the well inactivity or abandonment.

For these 35 wells, 54% reported either water quality or quantity problems:

- **8% of the water wells,** for a total of 3, reported water quality problems.
- **46% of the water wells,** for a total of 16, reported water quantity problems.

- **46% of the water wells,** for a total of 16, were reported to be inactive/abandoned due to corrosion failure, structural or mechanical problems, or pumping sand.

2.2.3 Potential Biofouling Symptoms

In the well inventory questionnaire, well owners were also asked questions that may be indicative of biofouling. Symptoms such as a decline in well yield, water quality deterioration, taste, odour, colour, presence of gas in the water, mineralization and slime on pumps were felt to be indicative of biofouling. Of the 131 active wells, 62% of the wells, for a total of 81, reported at least one of these symptoms. The questionnaire results for the symptoms that may be related to biofouling are provided in Table 2.

Potential Biofouling Symptoms	Statistical Data		Comments
	Numbe	Per cent	
Well yield decline	12	9%	most of these wells provide an inadequate water supply
Water quality deterioration	16	12%	responses from 129 of the 131wells; deterioration has been generally gradual or seasonal
Taste	31	24%	most reported this as a continual problem
Odour	30	23%	" rotten egg" odour was commonly reported
Colour	23	18%	most of these wells reported a slightly red or yellow colour
Gas in water	7	5%	hydrogen sulphide gas was most commonly reported
Mineralization	26	20%	generally reported as iron or "rust" deposits
Slime on pumps	9	7%	slime colour was either red, black or brown

Note: Table 2 indicates the responses that were received for the 131 active wells. Responses were not received for every well, so these numbers are conservative estimates.

TABLE 2 Potential Biofouling Symptoms

An attempt was made to determine if there was a relationship between the biofouling symptoms reported in Table 2 and the age of the wells. As shown in Table 3, the biofouling symptoms generally do not appear to be dependent on the age of the well, with the same average number of symptoms reported for wells ranging from 1-90 years old. The well age category from 21-30 years is the only group that has reported less symptoms.

Age of Well (years)	Statistical Data		Average Number of Potential Biofouling Symptoms Reported
	Numbe	Per cent	
1-10	12	11%	1.17
11-15	37	34%	1.14
16-20	18	17%	1.22
21-30	20	18%	0.67
greater than 30	22	20%	1.23

Note: Age information was available for 109 of the 131 active wells.

TABLE 3 Relationship between Well Age and Potential Biofouling Symptoms

3.0 MICROBIOLOGICAL AND NITRATE TESTING

The impact of naturally-occurring nuisance bacteria in groundwater has not been well understood, and losses in water well production and water quality deterioration have traditionally been attributed to the chemical and physical properties of the water well environment. However, less recognized is that groundwater contains microorganisms, and the activities associated with these microorganisms can reduce the value and life of a water well. Water well deterioration caused by microbiological activity is termed *biofouling* (Cullimore and Legault, 1997).

The purpose of the microbiological testing was to determine the extent and degree of biological activity in the water well environment and to compare these results to the symptoms reported by well owners. The most common tests used to determine the presence of biofouling in water wells are iron related bacteria (IRB), sulfate reducing bacteria (SRB) and heterotrophic aerobic bacteria (HAB). These three types of bacteria are often manifested in the following manner (DBI, 1999):

IRB - infestations usually occur in the presence of oxygen and commonly cause slimes, clogs or encrustations, discolouration of water or corrosion.
SRB - anaerobic bacteria that generate hydrogen sulfide (H_2S), which results in a variety of problems such as "rotten egg" odours, blackening of equipment and water, the appearance of black slime, and the initiation of corrosive processes.
HAB - aerobic bacteria that degrade organics as their source of energy and carbon. These bacteria cause much of the biodegradation that occurs under aerobic conditions and their presence may cause slime formation, strange taste and odours, and cloudiness in the water.

Nitrate testing was also conducted as part of this study. Nitrates in groundwater may be derived from the application of manure and agricultural fertilizers on farm land, septic tank seepage, livestock areas, or from geological formations containing soluble nitrogen compounds. High nitrate levels are generally an indication that the water may be contaminated with human/animal waste or with fertilizers. High nitrate levels are potentially harmful to infants, and therefore, the provincial guideline for nitrate has been set at 45 mg/L, as NO_3. Chemical fertilizers and nitrogen from human/animal waste may also serve as a potential nutritional source for the bacteria. Therefore, the nitrate test results were compared to the microbiological test results to determine if a correlation exists between the presence of nitrate and high bacteriological activity.

To minimize the occurrence of nitrates in groundwater, the source of nitrate must be understood. Nitrates are extremely soluble and easily migrate through the ground to the water table. Therefore, there may be some correlation between the near-surface soil materials and the occurrence of nitrates in water well supplies. To explore this further, wells with nitrate levels of 10 mg/L or greater were compared to the surficial geology of the area.

3.1 Methodology

Microbiological testing of the water samples was performed by PFRA using the Biological Activity Reaction Tests (BART™), which were developed by Droycon Bioconcepts

Incorporated(DBI) of Regina, Saskatchewan. A detailed description of this testing method is provided in the BART™ User Manual (DBI, 1999). These biodetectors offer a simple method for detecting the presence and activity level of selected groups of potential nuisance bacteria, which cause biofouling problems. In this study, the HAB-BART™ (heterotrophic aerobic bacteria), the IRB-BART™ (iron related bacteria) and the SRB-BART™ (sulfate reducing bacteria) were used for microbiological testing.

After the completion of the water well inventory, the microbiological testing was undertaken from September 26 to October 5, 2001. Water samples were collected from 50 randomly-selected wells identified in the water well inventory. Five additional wells were also sampled, since they were tank-loading wells operated by the R.M. of Mount Hope. The water samples were collected in sterile containers by a staff member from the PFRA Watrous District Office, placed in a cooler and sent for analysis, the same day, to the PFRA Technology Adaptation Facility in Regina. These samples were generally taken from the port (tap) closest to the well, usually at a hydrant or outside house tap. Before taking the sample the port was fully opened and allowed to run for five minutes. There were a few instances where owners were concerned about depleting their water supply while obtaining the water samples. Sampling times were then modified to accommodate the well owner and provide a suitable water sample for the testing.

At the PFRA Technology Adaptation Facility in Regina, the water samples were placed in the BART™ biodetectors and observed for a period of 10 days. The time elapsed from the addition of water to the biodetector until an initial reaction occurs is then recorded, which indicates the activity level of a bacteria group (i.e. the shorter the days to the first reaction, the more active the bacteria). When a water sample contains high levels of bacterial activity, biofouling is potentially occurring in the distribution system, water well or in the aquifer which supplies water to the well.

As part of the testing, water samples were also collected for nitrate analysis, using similar sampling procedures. These water samples were sent with the microbiological samples to the PFRA Technology Adaptation Facility in Regina, where the nitrate analysis was conducted using ion-selective electrodes (i.e. nitrate probes). These probes were used to identify water samples containing nitrate levels above 10 mg/L (as NO_3). Nitrate readings below 10 mg/l were considered to be below the detection limit of the probe, and therefore, were simply reported as <10 mg/L.

3.2 Microbiological Testing Results

The BART™analysis revealed that 43 (78%) of the 55 sampled wells contain at least one type of highly aggressive bacteria, which is generally indicative of biofouling. Also, almost all of the remaining wells have some type of medium aggressive bacteria. This is consistent with results from other studies, such as the M.D. of Kneehill study in Alberta, which indicate that biofouling is a progressive process (PFRA, 1997). Based on these results, biofouling will most likely occur to some degree in most of the wells in the study area. Detailed results of the BART™analysis are provided in Appendix A.

3.2.1 Iron Related Bacteria (IRB)

As shown in Figure 3, IRB appears to be the dominant bacteria, with 40 (73%) of the

sampled wells containing highly aggressive levels of IRB. Medium aggressivity levels were observed
in 8 (15%)of the wells and low aggressivity levels were observed in 4 (7%) of the wells. Three wells recorded no reaction. A comparison of these BART™results to the symptoms reported by well owners in the well inventory questionnaire show some correlation. The sampled wells that reported a slightly red colour all had high IRB levels, and about 50% of the sampled wells that reported high iron levels also had high or medium IRB levels. However, the ability to make significant comparisons is very limited, since the sampled wells were randomly-selected, and therefore, did not always include wells with biofouling symptoms.

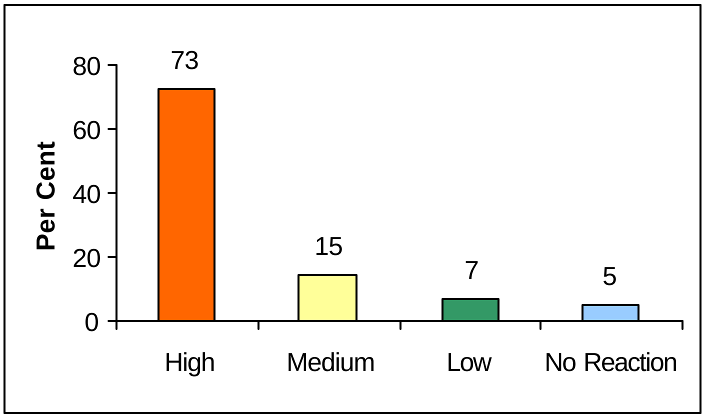


FIGURE 3 Iron Related Bacteria Activity Levels

3.2.2 Sulfate Reducing Bacteria (SRB)

Sulfate reducing bacteria are also present in many of the sampled wells, with 23 (42%) wells containing high levels of SRB, as shown in Figure 4. However, SRB are less dominant than IRB, with 23 (42%) of the sampled wells containing low activity levels of SRB or recording no reaction at all. When the BART™results are compared to the symptoms reported by well owners in the well inventory questionnaire, such as "rotten egg" odour, unpleasant taste, corrosion and the formation of black slimes, there is very poor correlation. Some of this is due to the fact that the sampled wells were randomly-selected, and therefore, the wells with biofouling symptoms were not always sampled. Also, since the samples were primarily "grab" samples, some wells may not have been pumped a sufficient length of time to obtain a representative water sample from the aquifer.

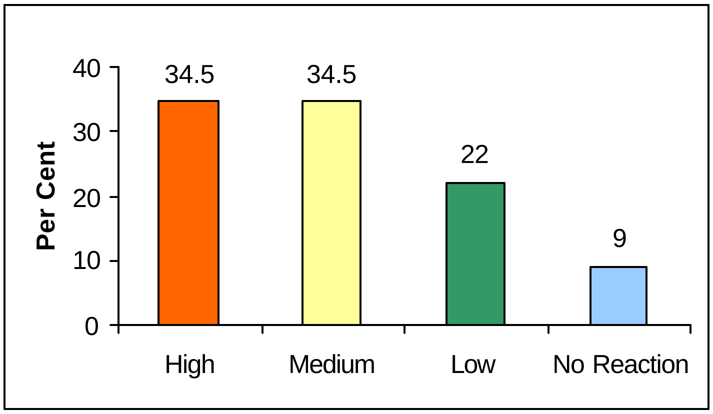


FIGURE 4 Sulfate Reducing Bacteria Activity Levels

3.2.3 Heterotrophic Aerobic Bacteria (HAB)

The HAB activity levels in the sampled wells are shown in Figure 5. The presence of high or medium levels of HAB is an indicator of a potential microbial problem. Other BART™s can be used to detect the specific types of bacteria present, such as the IRB-BART™ and the SRB- BART™ that were used in this study. As indicated in Figure 5, 69% (38) of the sampled wells have high or medium levels of HAB, and about 56% of these wells were also reported by the well owner to have a least one biofouling symptom.

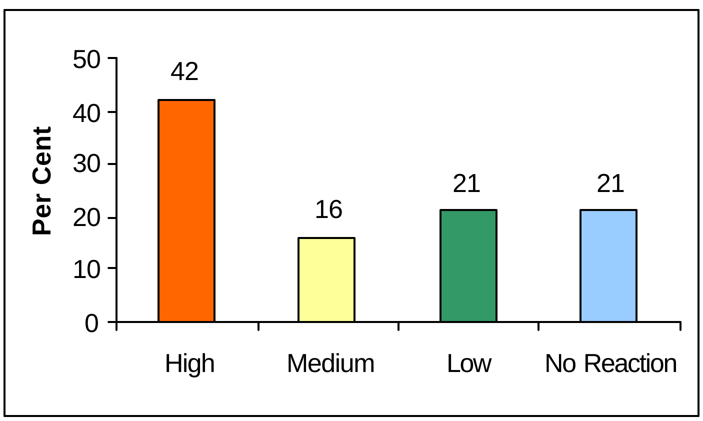


FIGURE 5 Heterotrophic Aerobic Bacteria Activity Levels

3.3 Nitrate Testing Results

In this study, of the 55 water samples collected, nitrate analyses indicated that 22 (40%) of the samples had nitrate levels of 10 mg/L or greater, and 10 (18%) of these samples had nitrates levels of 45 mg/L or greater. The general nitrate analysis results are shown in Figure 6.

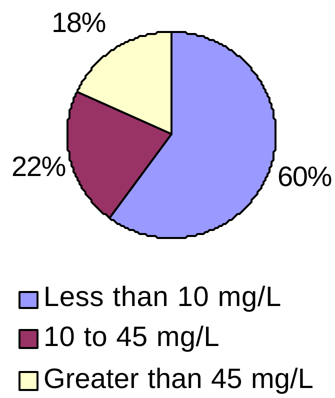
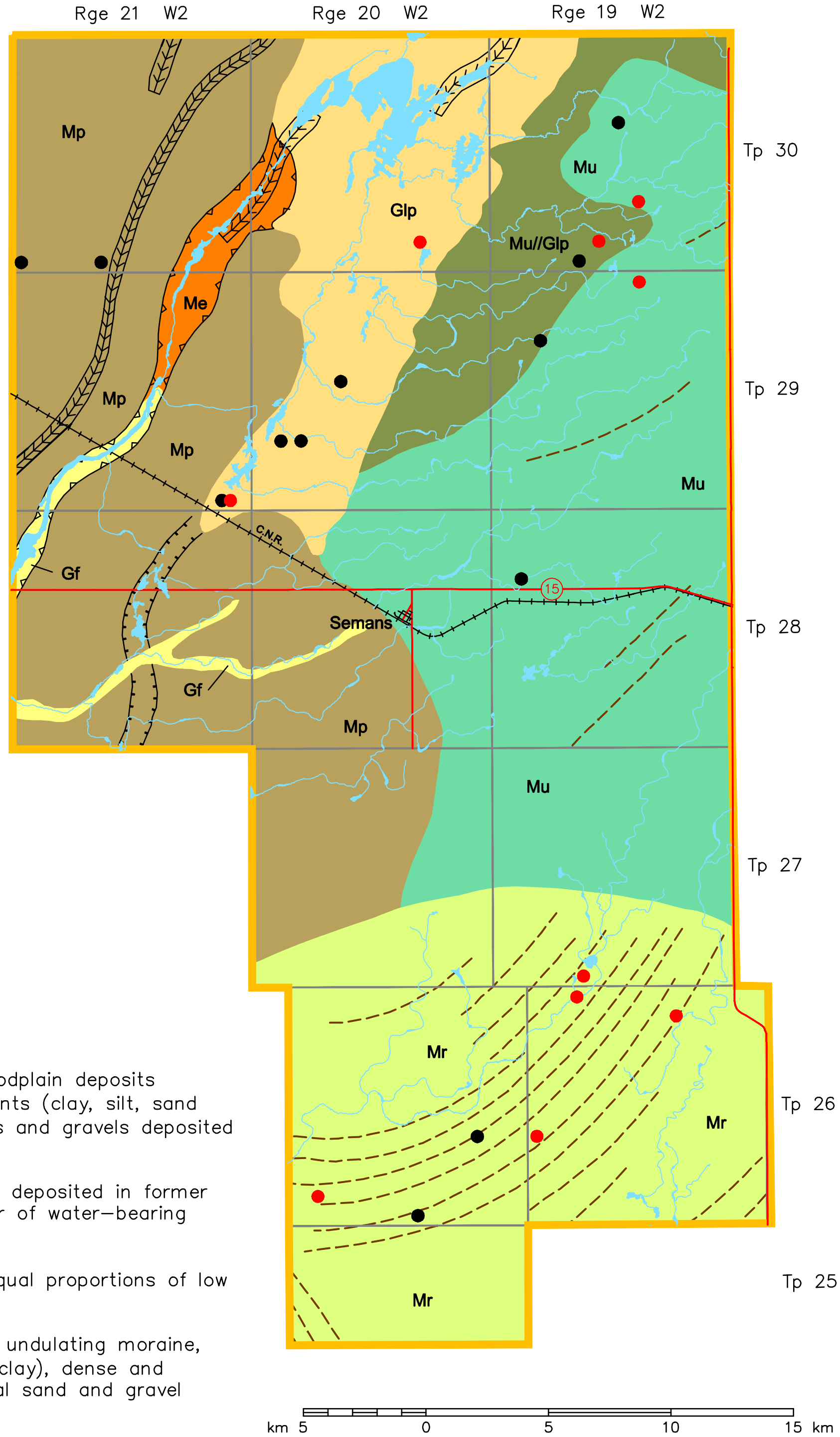


FIGURE 6 Nitrate Analysis Results

To explore the relationship between nitrate levels and surficial geology, nitrate levels reported to be 10 mg/L or greater were plotted on a surficial geology map for the area (see Figure 7). As illustrated in Figure 7, the wells with nitrate levels greater than 45 mg/L are generally located in glacial lacustrine deposits or ridged moraine deposits. A further inspection of air photos for the study area revealed that the wells located in these lacustrine plain deposits were usually within or near a creek channel, and these deposits appear to consist of silty or fine sandy soil material. Also, air photo inspection indicated that wells located in the ridged moraine deposits appear to be located in sandy soil material between these ridges. Both these areas represent locations where surface contaminants could easily migrate into the subsurface. In these areas, the wells are generally shallow in nature and are extremely susceptible to contamination.



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LEGEND

- ● Wells with nitrate levels 10–45 mg/L (as NO_3)
- ● (red) Wells with nitrate levels > 45 mg/L (as NO_3)
- Esker
- Ridged Moraine
- Extents of Buried Valley
- Extents of Meltwater Channel
- R.M. boundary

Gf Glaciofluvial: Includes Recent Channel and Floodplain deposits composed of variable–textured alluvial sediments (clay, silt, sand and minor gravel), overlying glaciofluvial sands and gravels deposited in a meltwater channel.

Glp Glaciolacustrine Plain: Clay, silt and fine sand deposited in former glacial lake basins; often includes a thin layer of water–bearing sand near the base of the unit.

Mu//Glp Morainal Undulating//Glaciolacustrine Plain: Equal proportions of low relief moraine and glaciolacustrine plain.

Mp Morainal Plain: Relatively flat–lying to slightly undulating moraine, composed gravelly, silty to sandy till (glacial clay), dense and compact with cobbles, boulders and occasional sand and gravel pockets.

Mr Morainal Ridged: Knob and kettle moraine exhibiting moderate to rough topography, composed of gravelly, silty to sandy till (glacial clay), dense and compact with cobbles, boulders and fairly abundant sand and gravel pockets.

Mu Morainal Undulating: Low relief moraine with gentle slopes.

Me Morainal Eroded: Glacial spillway or meltwater channel.

Reference: The extents of surficial geology shown on this plan were digitized from a paper map entitled "Aggregate Resource Potential and Surficial Geology of the Wynyard Area (72P) Saskatchewan", published by Sedimentary Resources, Saskatchewan Research Council (SRC) dated 1987. The SRC map was produced using a compilation of published and unpublished soil and geology information combined with aerial photograph interpretation of terrain patterns. Data from SRC's testhole files and minimal field checking provided site specific information.

Note: If this plan is reproduced, the reference to the original SRC maps must be included.

FIGURE 7 Surficial Geology and Nitrate Levels

4.0 DISCUSSION OF FINDINGS

The two main objectives of this study were to determine the state of water wells within the R.M. of Mount Hope, and to conduct microbiological (BART™) testing to assess the impacts of naturally-occurring nuisance bacteria on water wells in the area. Nitrate testing was also conducted concurrently with the microbiological testing to determine if a relationship existed between the presence of nitrate and biological activity in the wells, and to determine the impact surficial geology may have on the presence of nitrates in groundwater.

4.1 Water Well Inventory

The results of the water well inventory questionnaire revealed that the vast majority (90%) of the respondents were generally satisfied with their well yield. Water quality appears to be the primary concern, with 76 per cent of the wells reported to have at least one water quality problem. These problems were likely evident when the well was initially installed, since only 12 per cent of the wells reported a deterioration in water quality. The main water quality problem identified in the telephone questionnaire was the presence of iron, with over half of the wells reported to have high iron concentrations, which often caused water discolouration (i.e. slightly red or yellow colour), staining of plumbing fixtures and iron deposits within the distribution system. The questionnaire results also revealed that the most common treatment method used to deal with this iron problem was to install either a water softener or iron filter. Another indication that the overall water quality in the study area may be poor is that less than half of the wells were reported to be used as a drinking water source.

Although the data for abandoned or inactive wells is very limited, it appears that the main reason for well abandonment or inactivity is due to either reduced yield, or operational or structural failure of the well. Therefore, although water quality has been identified as a problem in the R.M., the problem is generally tolerated or treated rather than abandoning the supply. The results from the telephone questionnaire revealed that most of the wells that were abandoned or inactive had problems with well yield, well corrosion, and sand pumping (see Section 2.2.2), which are all potential symptoms of biofouling. Therefore, it is speculated that the majority of the abandoned or inactive wells are in their present state due to causes related to biofouling.

The average age of a well, prior to abandonment or inactivity, is calculated to be 18 years. A review of well ages in the R.M. also indicates that 34 per cent of the active wells were constructed 11-15 years ago, which implies that some of these wells would likely need to be replaced, or undergo some sort of well treatment or may even be abandoned in the near future. Most of these wells were installed during the drought in the 1980's, when federal and provincial government programs provided funding for well construction, which often became an incentive to replace a "poor" well. Currently, similar programs are not in place, which may result in extending the time before well replacement. Therefore, well treatment or well maintenance may become a more attractive option in extending well life. One additional observation, in regards to well ages, is that wells constructed 21-30 years ago are reported to have less biofouling symptoms than other wells in the R.M. (see Table 3). These are the wells that were not replaced during the well grant program in the 1980's, since they were probably not experiencing any major problems at the time. However, as these wells continue to age, the biofouling symptoms will likely increase, as shown by Table 3, and as stated earlier, unless well yield becomes unacceptable, well owners will likely tolerate any other problems rather than abandon the water well supply.

4.2 Microbiological and Nitrate Testing

Microbiological testing revealed that almost 80 percent of the sampled wells contain at least one type of highly aggressive bacteria, which implies that these wells are at some stage of biofouling. Iron related bacteria are the most prominent nuisance bacteria in the study area (see Figure 3), and may present itself as slime deposits in the well or on plumbing fixtures, "rust" or iron deposits and well corrosion. In severe cases, plugging of the well intake may occur, which may also reduce the well yield. However, a reduction in well yield may not always be noticeable, since the Sask Water water well database indicates that the recommended well yields in this area are generally greater than the average daily household water requirements. Therefore, if some biological plugging does occur, a slight reduction in yield would probably not affect the ability of the well to provide an adequate water supply, and would likely not be noticed by the well owner.

Attempts were also made to correlate biofouling of the wells, as indicated by the BART™ results, with well construction details, well depth, well age, and water quality parameters, such as iron and nitrate. In conducting these comparisons, it was found that well construction materials do not appear to influence the presence of biofouling, since construction materials for the biofouled wells varied from porous concrete, steel, galvanized steel, PVC, fibreglass and wood. Well depth and well age also had no effect on the presence of biofouling, as both shallow (<15 m) and deep (>15 m) wells were subject to biofouling indications, with well ages ranging from 1 to 56 years. There also appears to be no direct correlation between the occurrence of high bacteriological activity in a well and the reported iron and nitrate levels. The study results showed that about 50 percent of the wells that contained at least one type of highly aggressive nuisance bacteria were reported by well owners to have high iron levels, and about 50 percent of the wells that contained at least one type of highly aggressive nuisance bacteria had detectable levels of nitrate (>10mg/L). In wells that had recorded a high activity for all three types of bacteria, there appears to be a better correlation between the high biological activity and nitrate levels. From these 13 wells, 8 wells had nitrate readings in excess of 10 mg/L, with 5 of these wells recording nitrate levels in excess of the provincial guideline of 45 mg/L (as NO_3).

According to this study, shallow wells located in areas with silty and sandy near-surface materials are more susceptible to the downward movement of surface contaminants, including nitrates. Wells in the study area, with nitrate levels in excess of 45 mg/L, were usually situated within natural drainage courses and in areas where the surface materials consist of silty fine sand or sandy till, as indicated by the surficial geology map (see Figure 7) or identified by air photo inspection. Therefore, land practices must be properly managed and wells properly sited to reduce the risk of water well contamination.

The preliminary nitrate testing conducted, as part of this study, revealed that elevated nitrate levels even occurred in wells that were reported by the well owner to have no water quality problem. Therefore, a well owner's perception is not always indicative of the actual water quality. The presence of nitrate may also signal that other contaminants could easily migrate into the water well environment. Therefore, if elevated nitrate levels are encountered, the well should be tested for the presence of coliform bacteria, and any land activities/practices identified that may represent potential sources of contamination. In these cases, site inspections should be carried out and mitigative measures implemented to reduce nitrate levels, with periodic monitoring of nitrate levels conducted to ensure that levels are not increasing.

Laboratory research, related to other water well biofouling projects involving PFRA, indicates that it may take a number of years for biological activity to affect a water well supply. Owners who pump their wells at rates less than the well's capacity would likely not notice a progressive reduction in yield due to biofouling, unless they were carefully monitoring their well. Other factors, such as well design, construction, and operation, combined with subtle differences in aquifer conditions (i.e. hydraulic conductivity), formation differences or well development differences will also have an effect on the rate of biofouling (Smith, 1995). In addition, well owners with water treatment equipment may not immediately notice a change in water quality, until the treatment applied can no longer effectively treat the problem. This underscores the importance of monitoring well performance and testing water quality on a regular basis.

Although highly aggressive levels of nuisance bacteria may not always cause reduced well yields or a deterioration in water quality, the presence of these nuisance bacteria may still effect the overall water well environment. Over the years, as the nuisance bacteria colonize and continue to grow, the biofilms that are created act as a filter, accumulating particulate matter that is transported to the well or dissolved minerals that are precipitated at the well intake. These biofilms may also harbour bacteria that pose a hygiene risk. Periodically, the biofilms will also shear or slough, allowing the biofilm material to move into the water distribution system. This may temporarily affect the water quality, in terms of taste, discolouration, odour, staining or may even represent a potential hygiene risk. Therefore, it is important that biofouling symptoms in a well not be ignored, and that regular maintenance or treatment procedures be implemented if biofouling is suspected.

5.0 CONCLUSIONS

1. A total of 193 water wells were identified in the R.M. of Mount Hope and information was collected for 183 of these wells from the well owners' responses to a telephone questionnaire. Of these 183 wells, 131 wells were active and 52 wells were either abandoned, inactive or stand-by.

2. Of the 131 active wells, 118 (90%) were reported to provide an adequate yield, and only 12 (9%) were reported to have a noticeable reduction in yield. However, only 60 (46%) wells are reported to be used for drinking water. Therefore, it is suspected that water quality may be the limiting factor for its use as a drinking water source.

3. General water quality information was received for 129 of the 131 active wells, with 62 (48%) reporting excellent or good water quality, and 67 (52%) reporting fair or poor water quality. However, only 16 (12%) of these wells reported a noticeable deterioration in water quality. Therefore, it appears that most of the reported water quality problems were likely present when the well was initially installed.

4. The well owners' responses to the telephone questionnaire revealed that 99 (76%) of the active wells reported at least one water quality problem, which included high iron, odour, colour, particulate matter in the water, gas, staining and unpleasant taste. Iron appears to be the most predominant problem, with 71 (54%) reporting high iron levels and 55 (42%) reporting staining of plumbing fixtures.

5. Limited data is available on the 52 wells reported by well owners as abandoned, inactive or stand-by. Of the 35 wells that reported reasons for abandonment or inactivity, 32 (92%) had well yield, well corrosion, structural problems or sand pumping problems. Therefore, although water quality has been identified as the main concern in the R.M., a water quality problem is generally tolerated or treated rather than abandoning the supply.

6. Biofouling is present in many of the wells within the R.M. of Mount Hope. Of the 131 active wells, 62% of the wells, for a total of 81, reported at least one biofouling symptom, and 43 (78%) of the 55 sampled wells contained at least one type of aggressive nuisance bacteria. Iron related bacteria (IRB) appears to be the most prominent type of nuisance bacteria, with 40 (73%) of the sampled wells containing highly aggressive levels of IRB.

7. Shallow wells located in areas with silty and sandy near-surface deposits are more susceptible to nitrate contamination. The nitrate analyses, from the 55 sample wells, revealed that 22 (40%) of the wells had nitrate levels of 10 mg/L or greater, and 10 (18%) wells exceeded the provincial guideline of 45 mg/L. All, but one of the wells, with nitrate levels above 45 mg/L were shallow wells (<15 m), which were generally located within silty to sandy surficial deposits.

6.0 RECOMMENDATIONS

1. Biofouling appears to be present in most of the wells within the R.M., which may affect either the yield or quality of the water supply. Therefore, if biofouling is suspected to be occurring, it is recommended that regular maintenance/treatment procedures be implemented to control the effects of biofouling.

2. If elevated nitrate levels are encountered in a well, a site inspection is recommended to identify potential sources of nitrate contamination. It is also recommended that the potential impact of any land activities/practices on the groundwater supply be assessed. Mitigative measures must be taken immediately to reduce the nitrate levels and periodic monitoring of nitrate levels is recommended to ensure that nitrate levels are not increasing.

3. Regular testing for coliform bacteria should be conducted on any potable water source. In cases where elevated nitrate levels are encountered or extremely high biological activity is observed, it is recommended that the frequency of coliform testing be increased.

4. As a precautionary measure, it is recommended that any well that has been permanently abandoned should be properly sealed to ensure that it does not become an avenue for potential contaminants to migrate into the subsurface.

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APPENDIX A:

Microbiological and Nitrate Analysis

Microbiological Analysis Using The BART™ System

The Biological Activity Reaction Test (BART™) system was developed by Droycon Bioconcepts Inc. (DBI) of Regina, Saskatchewan. The 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 most common tests used to identify bacteria groups in water wells on the Canadian Prairies are the IRB, SRB, and HAB.

1) The BART™ System

The simplicity and unique nature of the BART™ system makes it very useful in detecting the nuisance bacteria involved in water well biofouling. In addition, the BART™ system provides a wide variety of environments within which a particular bacteria can grow. In conducting the test, a 15-ml water sample is collected and placed directly into the plastic BART™ vial. The plastic test vial contains a floating ball which restricts the amount of oxygen entering 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 are better able to adapt and grow if the crystallized medium is suitable for their growth.

2) BART™ Data Interpretation

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 (Table A1) is a summary of the data, supplied by DBI, which is used as a guide to determine the aggressivity levels of IRB, SRB, and HAB in a water sample. A BART™ data interpretation chart is also provided in Figure A1.

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 -5	1 - 2
Medium	5 - 8	6 - 8	3 - 4
Low	9 - 10	9 - 10	5 - 10

Table A1: Determining Bacterial Aggressivity Levels

A list of the possible reactions (RX) is included with the test kits or can be obtained from DBI. 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.

Note: the above information was adapted from the BART™ User Manual (DBI, 1999).

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)

Note: obtained from www.dbi.sk.ca; May 2000

FIGURE A1 BART™ Interpretation Chart

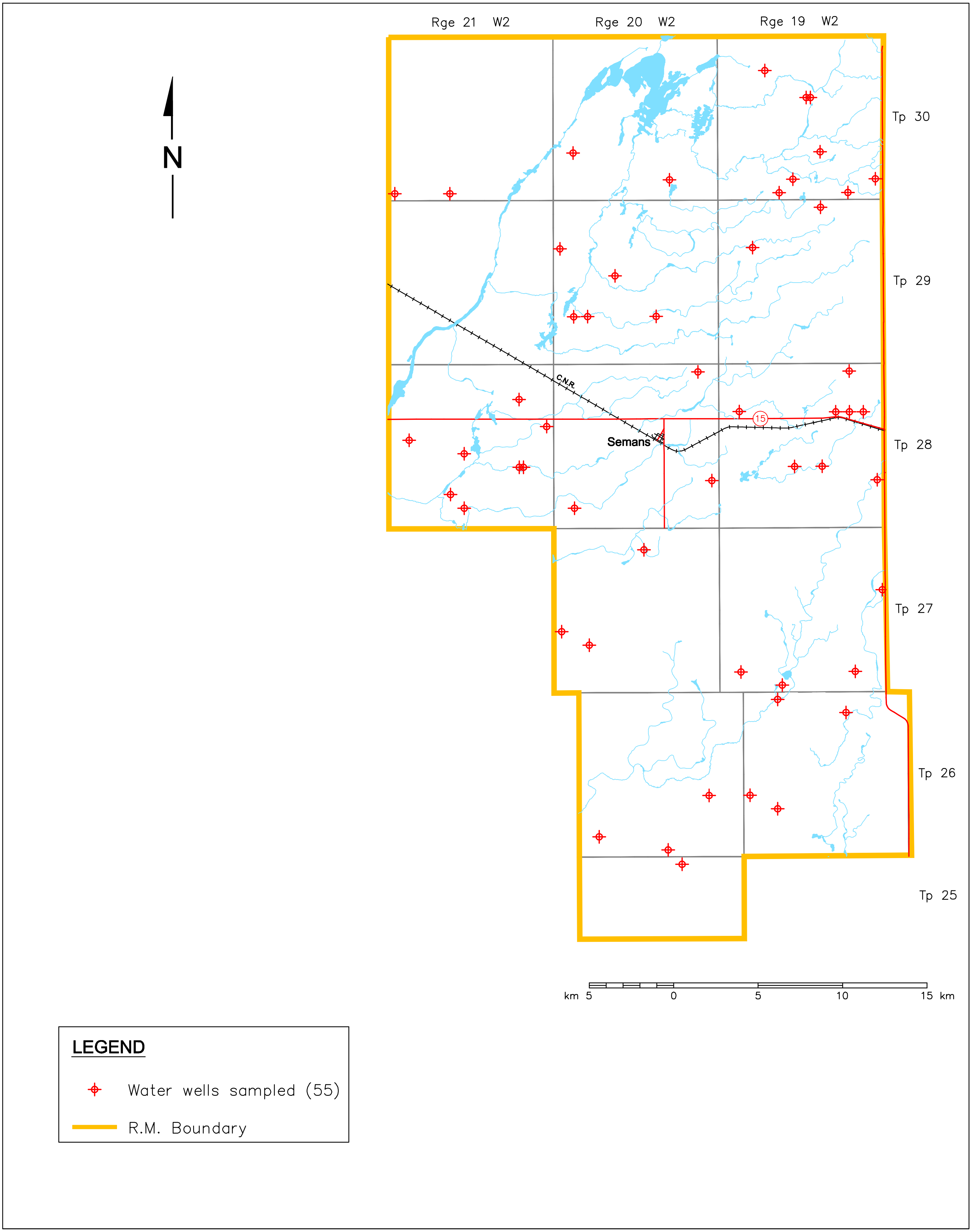

FIGURE A2 Microbiological and Nitrate Testing Sites

TABLE A2: Biological Activity Reaction Tests (BART™) and Nitrate Analyses

Sample Number	IRB dd/rx	IRB Aggressivity	SRB dd/rx	SRB Aggressivity	HAB dd/rx	HAB Aggressivity	Nitrate mg/L as NO_3	Well Depth (feet)
1	3 FO	High	10	NR	3 DO	Medium	<10	230
2	4 FO	High	10	NR	4 DO	Medium	<10	195
3	4 FO	High	4 BB	High	10	NR	<10	20
4	3 FO	High	2 BT	High	4 DO	Medium	<10	8
5	3 FO	High	4 BT	High	2 UP	High	<10	NA
6	10 FO	Low	10	NR	10	NR	<10	300
7	10	NR	6 BT	High	4 DO	Medium	<10	210
8	3 FO	High	2 BT	High	4 DO	Medium	<10	85
9	3 FO	High	10	NR	4 DO	Medium	<10	255
10	3 FO	High	3 BT	High	2 UP	High	215	28
11	3 FO	High	2 BT	High	2 UP	High	78	37
12	4 BC	High	2 BT	High	2 UP	High	42	20
13	4 BR	High	3 BT	High	2 UP	High	200	26
14	3 FO	High	10	NR	2 UP	High	23	30
15	3 BR	High	7 BB	Medium	5 UP	Low	15	45
16	3 FO	High	10	NR	3 DO	High	107	40
17	4 FO, CL	High	4 BT	High	2 DO	High	53	28
18	3 FO	High	4 BA	High	2 DO	High	144	95
19	3 FO, BR	High	5 BB	High	5 BD	Low	<10	170
20	3 FO	High	3 BA	High	2 DO	High	38	48
21	5 FO	Medium	10	NR	5 DO	Low	<10	255
22	10	NR	9 BB	Low	4 DO	Medium	<10	340
23	3 FO	High	10	NR	3 BD	Medium	45	30
24	5 FO	Medium	10	NR	4 DO	Medium	<10	40
25	4 FO	High	7 BT	Medium	4 DO	Medium	15	8
26	4 FO	High	10	NR	2 UP	High	10	486
27	9 CL	Low	4 BB	High	2 DO	High	<10	120
28	3 FO	High	10	NR	5 DO	Low	16	NA
29	4 CL	High	10	NR	2 BD	High	131	12
30	4 FO, BC	High	2 BT	High	2 BD	High	<10	135
31	5 FO	Medium	6 BT	Medium	5 UP	Low	<10	127
32	4 FO, BC	High	10 BB	Low	3 UP	Medium	10	365
33	6 BR	Medium	8 BT	Medium	4 DO	Medium	39	13
34	8 BR	Medium	8 BB	Low	NR	NR	<10	112
35	6 FO, CL	Medium	9 BT	Low	NR	NR	<10	517
36	4 FO, BC	High	10 BB	Low	8 UP	Low	<10	350
37	3 FO, CL	High	6 BT	Medium	3 DO	Medium	<10	39
38	6 FO, BC	Medium	10	NR	6 UP	Low	<10	380
39	3 BL	High	2 BB	High	2 DO	High	<10	90
40	6 FO, BC	Medium	6 BT	Medium	6 DO	Low	<10	273
41	3 FO, BR, BC	High	10	NR	10 UP	Low	<10	280
42	4 FO, BC	High	8 BT	Medium	2 DO	High	<10	50
43	3 FO	High	2 BB	High	2 DO	High	<10	500
44	3 FO	High	10	NR	4 DO	Medium	38	12
45	9 BR	Low	8 BT	Medium	7 DO	Low	<10	79
46	3 FO	High	2 BB	High	2 DO	High	16	NA
47	3 FO	High	4 BB	High	3 DO	Medium	65	NA
48	4 FO, BC	High	6 BT	High	4 DO	Medium	<10	280
49	3 FO	High	5 BT	High	4 DO	Medium	<10	450
50	3 FO, BC	High	4 BT	High	4 DO	Medium	<10	505
51	10	NR	10	NR	6 DO	Low	<10	200
52	3 FO	High	6 BB	Medium	5 DO	Low	75	14
53	3 FO	High	3 BT	High	2 DO	High	<10	80
54	10 BR	Low	10	NR	10	NR	<10	14
55	3 FO	High	10	NR	4 DO	Medium	42	200

dd - days of delay
rx - reaction type (see Figure A1)
NA - Not Available
NR - No Reaction
BD - Bleached (bleaching direction not noted)