Overcoming Screen Collapse in a Test Well

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ABSTRACT
The Town of Shubenacadie, Nova Scotia is exploring groundwater near Route 102 as a potential drinking water source. Stantec designed a 200 mm production well intersecting buried glaciofluvial channels. Two well screens were installed to intersect the channels, and one screen collapsed to roughly 1/4 the original diametre during development. Rather than abandon the well, it was opted to attempt to rehabilitate the screen and restore the well's usability. As a result of the efforts, the cross-sectional screen opening was increased to about 2/3 its original diametre and the estimated flow from the well more than doubled as development continued. Hydraulic testing was completed at 11.4 L/s (150 igpm) over seven days, indicating a productive aquifer that met our target yield.

RÉSUMÉ
La Ville de Shubenacadie, Nouvelle Ecosse explore la nappe phréatique près de la route 102 comme une ressource d'eau potable potentielle. Stantec a conçu un nouveau puits de 200 millimètres croisant bien des dépôts glaciofluviaires. Deux crépines ont été installés pour croiser les dépôts et une crépine s'est effondré à environ un quart du diametre original pendant le développement. Plutôt qu'abandonner le puits, nous avons opté de réhabiliter la crépine et restituer l'utilité du puits. À la suite des efforts, l'ouverture de la crépine a été augmentée à environ 2/3 de son diametre original et l'écoulement d'eau estimé à été doublé. La mise à l'essai hydraulique a été accomplie à 11.4 L/s (150 igpm) durant sept jours, indiquant une couche-aquifère productive qui peut satisfaire la demande de réserves de la ville.

1 INTRODUCTION

With increasing demand on treatment for surface water supplies in the province of Nova Scotia, the Town of Shubenacadie sought a groundwater source to replace the existing surface lake water supply. Groundwater tends to require less treatment and is generally less susceptible to sudden contamination than surface water sources.

An area was identified by others within the Town in the confined Shubenacadie-Milford Aquifer Complex (SMAC), and the Town has focused on this area to develop the groundwater resource over the last several years. The most recent work involved construction of a test well with two pipe-size screened intervals to intersect the most productive sand layers. Because of previous investigations, up to 10 monitoring wells were available for observation during our hydraulic testing.

After designing and installing the test well, a significant problem was encountered during development of the two well screens. Down hole well videos confirmed that the lower screen, situated between approximately 26 and 29 m below surface, had experienced lateral collapse. This presented a significant challenge for the remaining work, and raised a critical choice: Should the test hole be abandoned and attempt a new location, or can the well screen be rehabilitated in order to continue in this location?

2 AREA HYDROGEOLOGY

The SMAC is a confined Cretaceous-age sand and gravel aquifer underlying parts of the Shubenacadie River valley, and its extents have previously been delineated showing it to be a long, thin complex trending north-south through the valley. A general site location within Nova Scotia is presented in Figure 1. The aquifer has previously been subject to exploration and testing by others, and has presented several challenges at each attempt while promising adequate yield to meet the municipal demand.

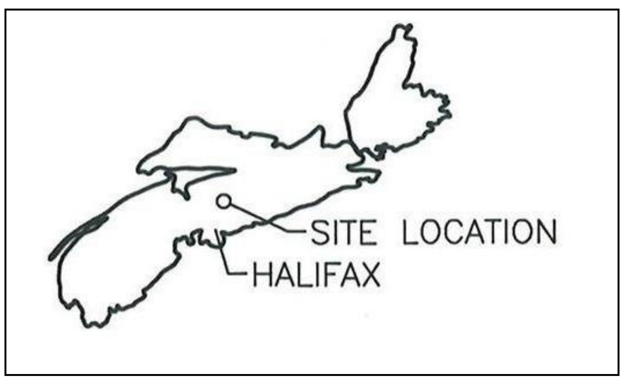

Figure 1. Site location within Nova Scotia, Canada.

The area was first considered in Lay *et. al.* (1979), where "*the greatest groundwater potential probably exists within the entire Shubenacadie/Stewiacke watersheds*" and it was noted that several wells in the area yield over 100 igpm. He continues that "*this type of surficial aquifer may produce large quantities of good quality water from properly constructed wells*" (Lay *et. al.* 1979). From several locations, the aquifer appears to consist of two productive sand layers separated by clay-silt and protected by thick clay till near ground surface. Previous research and testing in the area by Matheson (1999) has identified roughly the aquifer's local boundaries as shown in Figure 2. The outer dashed lines on either side of PW11 indicate the mapped extents of the aquifer.

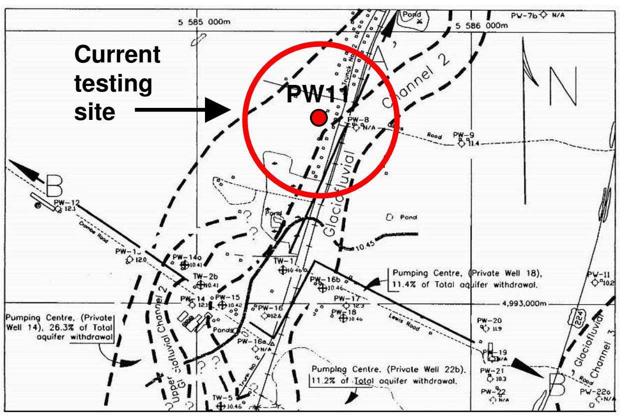

Figure 2. Generalized hydrogeology of the SMAC near the testing site (from Matheson 1999).

The SMAC is confined by a clay till of varying thickness, and has over 15 m at the testing site. Potentiometric groundwater levels as historically measured from monitoring wells in the SMAC are significantly higher than the top of the aquifer/bottom of the clay till, in the order of 10 m, suggesting that the aquifer is indeed confined and subject to artesian pressures. The aquifer is also subject to barometric pressure effects in a manner that is consistent with confined aquifers (Freeze and Cherry 1979).

The aquifer material itself as defined from previous studies and the current investigation consists of silica-rich fine to medium sand, with some clay mineral content possibly including kaolin. Previous hydraulic testing in the SMAC determined aquifer transmissivity to vary between 200 and 2000 m^3/day, and storativity ranging between 1×10^{-3} and 6×10^{-4} (Matheson 1999).

Over the past decade, challenges with drilling, well construction and development have contributed to yields that were either inconsistent or lower than expected, as the resource itself has historically proven difficult to develop. Based on the aquifer material, vertical and horizontal extents of the aquifer and recharge areas, a generous supply of groundwater in the SMAC was always suggested but never quite realized.

3 WELL CONSTRUCTION

In January 2008 a pilot sample hole was completed at the test site. Soil samples retrieved from the pilot hole show over 10 m of clay till, followed by 7 m of dense grey clay, then alternating medium sand and brown silt-clay to 30 m. Two productive zones of medium sand were identified, at depths of 19 to 22 m and 25 to 29 m.

3.1 Initial Well Installation

The two productive intervals in the pilot hole were chosen for well screen placement, and soil samples from each interval were analyzed for grain size distribution. Well screens were designed based on the grain size results, with a 50 percent passing ratio (up to 1 mm). Both sections are 30-slot 200 mm pipe size continuous wire-wrapped screen. The native grain size distribution suggested a natural filter pack could be developed for the well screens.

Test well PW11 was installed in the exact location of the pilot hole in February 2008 with well screens from 20.3 to 22.1 and 25.9 to 29.0 m. The well was installed using bentonite drilling mud with a high Marsh viscosity (55 to 60 seconds) to stabilize the borehole.

Preliminary well development started immediately after the well was installed to develop the natural filter pack, and proved slow in removing drilling mud from the aquifer. Little water return was noted during development using air surging and a jetting tool. Resistance to the drill rods and jetting tool was encountered at a depth of approximately 28 m, and development was stopped at that time in order to record a down hole well video.

3.2 Down Hole Well Video: Pre-Treatment

The initial well video in February 2008, immediately after resistance was encountered, shows that the lower well screen had a horizontal collapse beyond 28 m depth, with a clearance of less than 5 cm (2 inches) in the centre – roughly 1/4 of the original diameter.

Figures 3A through 3F show still captures from the down hole video, indicating the collapsed screen and showing affected pinched areas. Photos 3A, 3C and 3E show the screen looking down while photos 3B, 3D and 3F show side-on views of the screen at approximately corresponding depths.

Near the top of the screen, in Figure 3A, there are no visible signs of damage. A distance of 0.4 m further down shows some evidence that lateral pinching may have occurred, and the screen begins to appear slightly deformed (Figure 3B). Figures 3C and 3D look down and sideways, respectively, at the same depth and show significant deformation and lateral buckling.

Slightly deeper in Figures 3E and 3F, effects of the collapse are clearly visible. This is near the most constricted section of screen, and the camera would not pass much beyond this depth. Only a 5 cm opening remained in the 20 cm diametre screen. This was not sufficient to allow clearance for drilling or pumping tools, and would undoubtedly affect the test well's performance.

Figure 3A. 27.0 m near the top of the lower screen looking down. No visible signs of damage.

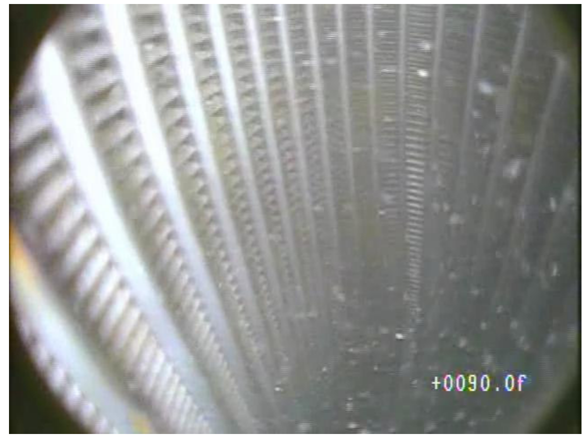

Figure 3B. 27.4 m looking sideways. Lateral pinching of the screen is becoming evident.

Figure 3C. 28.0 m looking down. The horizontal screen collapse can be seen with the left and right sides pinching in toward the middle.

Figure 3D. 28.0 m looking sideways. More evidence of pinching, and the left and right sides of the screen appear flat.

Figure 3E. 28.4 m looking down through the narrowest section of the collapsed screen. Only a 5 cm opening remained in the 20 cm diametre screen.

Figure 3F. 28.3 m looking sideways near the narrowest section of the collapsed screen. Distortion of the screen's shape is obvious.

3.3 The Collapse

From all indications in the field and on the down hole well video, excessive lateral stress some time after installation and during development led to failure of the lower well screen material. Two sides of the screen buckled horizontally, pinching the inside of the well screen effectively reducing the diametre of the vertical passage through the screen in that interval.

The video inspection indicated that the weld joining the top of screen to the well casing was intact, and it was assumed that the bottom weld was also intact. In this case, horizontal buckling of the well screen would have produced an hourglass shape as illustrated in Figure 4.

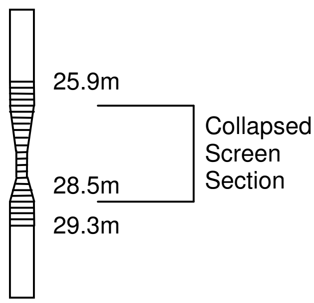

Figure 4. Simple illustration showing lateral well screen collapse beyond the approximate depth of 28 metres.

Calculations of lateral earth pressures at the screen depth indicated that the screen construction should have held, and design checks by a representative from Johnson Screens confirmed this position. However, given enough viscosity the drilling mud could possibly account for lateral well screen failure – if the mud cake surrounding the well was impervious enough to prevent natural groundwater from entering the screen for an extended time, then it is possible that the difference in pressure inside the well (dry) versus outside the well (saturated) could lead to this type of failure. The exact collapse mechanism has not been determined, and our objective was not to conduct a forensic analysis on the screen; rather, it was to improve the situation, if possible.

At this point, the team devoted much consideration to how the program should proceed. It became clear that abandoning this test well location was not preferred until no other course of action was available. Ultimately a plan was formed to repair the screen, involving jetting and gently forcing a small diametre well point through the collapsed portion to open the interior of the screen.

4 REHABILITATING THE WELL SCREEN

Stantec assembled a team to address the collapsed well screen, including Johnson Screens (manufacturer, Michigan, USA), the well driller and supplier (New Brunswick, Canada), the municipality (East Hants, Nova Scotia) and Stantec technical personnel. In April 2008 we returned to the field to initiate the lower screen repairs.

4.1 Well Screen Repair

The main repair apparatus consisted of a 13 cm threaded steel well point with jetting holes installed on the sides and bottom, connected to standard 10 cm diametre drill rods. Photos / schematics will be presented. The point was slowly pushed through the damaged screen section while air was jetted through the point against the screen. This process was repeated several times, varying the downward force and air pressure supplied by the drill rig.

After one half hour of continuous gentle expansion, the point would raise and lower through the collapsed section of well screen with minimal resistance. The physical rehabilitation of the well screen material was therefore successfully complete, and the focus shifted to well development to remove the drilling mud cake between the well and the formation and develop the natural filter pack around each screen.

During subsequent air development, the point was repeatedly pushed through the collapsed area and the screen retained a functional interior opening. Continued well development showed increasing yield from the screened areas, as indicated in Table 1. The table also indicates a classic surge and collapse yield pattern during development, varying generally between 30 and 60 igpm.

Table 1. Fluctuating well yield with development before, during and after rehabilitation of the well screen.

Date and Time	Hours into development	Approximate well yield (igpm)
27-Feb-08 6:00pm	2	10
28-Feb-08 2:00pm	8	17
28-Feb-08 3:00pm	9	23
28-Feb-08 4:00pm	10	30
14-Apr-08 4:00pm	11	40
14-Apr-08 5:00pm	12	50
15-Apr-08 2:00pm	18	30
15-Apr-08 6:00pm	22	40
16-Apr-08 4:00pm	30	24
17-Apr-08 12:00pm	34	40
17-Apr-08 1:00pm	35	60
17-Apr-08 2:00pm	36	20
17-Apr-08 4:00pm	38	40
18-Apr-08 6:00pm	40	60
28-May-08 2:00pm	73	150

4.2 Down Hole Well Video: Post-Treatment

The well video on April 17, after repair and development efforts on the well screen, shows that the screen diametre was effectively increased to approximately 13 cm, or 64 percent of the original diametre.

Figures 5A through 5F show video captures from the second video, indicating rehabilitated sections of the screen and some minor collateral damage during the repair process. Figures 5A and 5C through 5F show how the rehabilitation basically restored the well screen's circular geometry through the collapsed section.

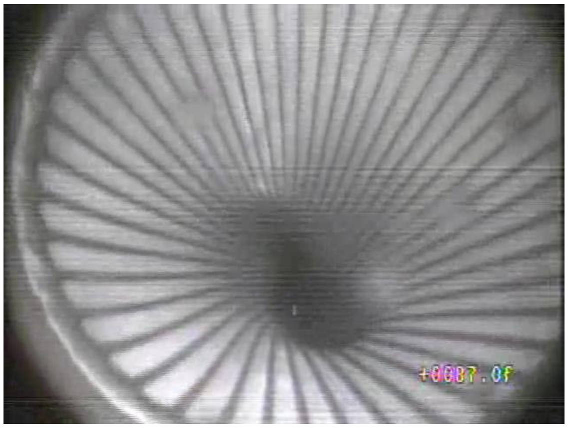

Figure 5A. 26.5 m looking down from the top of the screen. Some distortion remains, and repair efforts have increased the diametre to 13 cm in the centre.

Figure 5B. 26.7 m looking sideways through the 30 slot screen. Medium sand grains are seen against the screen, forming a natural filter pack.

Figure 5C. 27.8 m looking down through the area that had been constricted by the horizontal collapse.

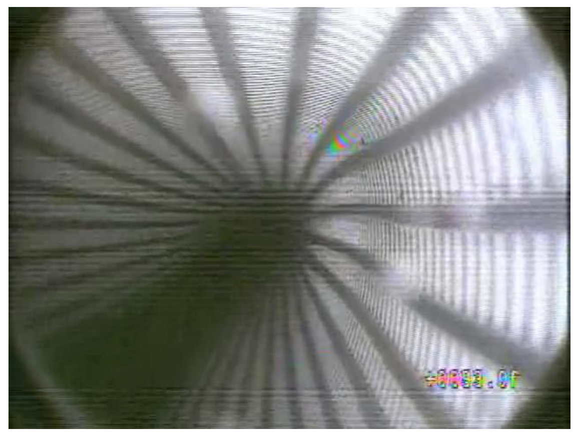

Figure 5D. 28.3 m looking down through the area that had been constricted by the horizontal collapse.

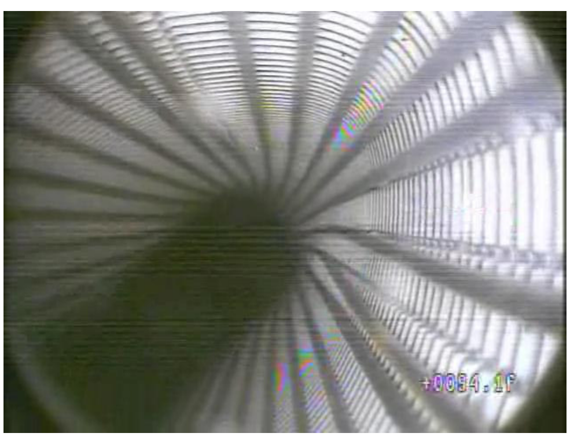

Figure 5E. 28.7 m looking down toward the bottom of the lower screen. Four vertical support rods were dislodged in places due to the aggressive repairs.

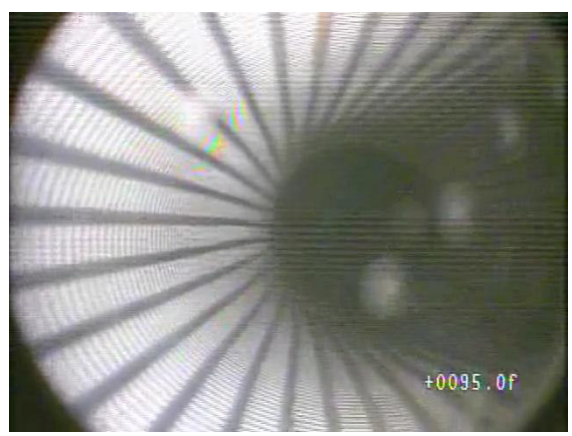

Figure 5F. 29.0 m looking down through the area that had been constricted by the horizontal collapse. The entire lower screen length was accessible.

Figure 5D shows the rehabilitated screen at 28.3 m depth, compared to the collapsed screen at the same depth in Figure 3E. Some vertical support rods were slightly dislodged during the repair process, as indicated most clearly in Figure 5E (four are visible of a total 44 rods). Note that Figures 5E and 5F are at depths that could not be reached with the camera pre-treatment.

The well video also indicated coarse grains against the upper screen, suggesting significant mud removal and a developing filter pack, and the screen capture in Figure 5B shows a mixture of coarse and fine grains against the lower screen.

4.3 Measuring Success

Once the lower well screen was rehabilitated, well development was re-initiated using a combination of air lift jetting and surging.

Well development using air lift jetting was completed after approximately 40 hours over the span of four days. Table 1 shows an estimated yield of 10 igpm at the onset of development, climbing to 30 igpm just prior to the lower screen collapse in February 2008. The measured well yield after air-lift development was completed had doubled to an estimated 60 igpm (Table 1).

Development was continued using surge blocks for an additional 33 hours over 3 days with visible success in sand removal and rapid water recovery, becoming less productive as sediment removal diminished and water cleared more quickly after surge cycles (Figure 6). Hydraulic step tests conducted at three intervals during cable tool surging – 5 hours, 24 hours and 33 hours – suggested steady improvement of the well's performance, as discussed in Section 5.

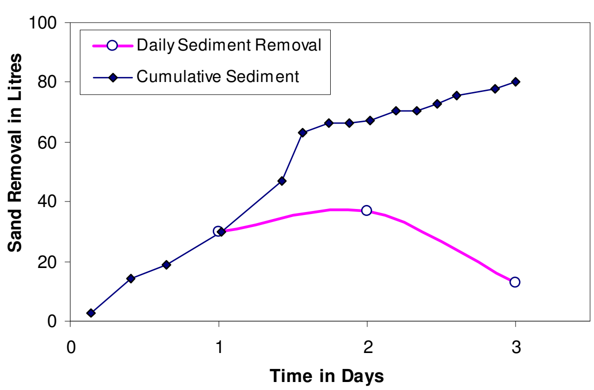

Figure 6. Daily and cumulative sand removal from the test well during surging. Cable tool development continued until diminishing returns were noted.

The most important measure of success throughout development and hydraulic testing was the integrity of the lower well screen, which held its repaired shape and its ability to continually produce groundwater that contributed to the overall well yield. Occasional pumping in the test well since that time has shown no indication of the screen losing hydraulic efficiency.

5 FINAL ANALYSIS

Hydraulic data from the three step tests provided the clearest indication of the test well's performance after the screen repair was complete. Linear fit plots for data at each of the three hydraulic step tests were used to assess the test well's performance and are presented in Figure 7. The plots show increasing specific capacity with development time, as indicated by the decreasing slope of each fit line (particularly between the early test at 5 hours and the two later tests), which should be expected in a "normally" behaving pumping well.

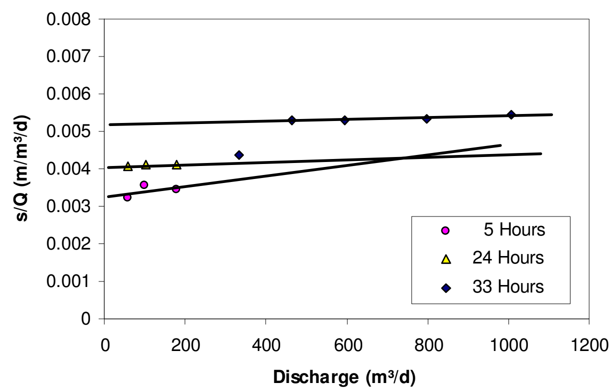

Figure 7. Linear fit plots for specific capacity at each hydraulic step test.

Table 2 shows well performance indicators from the hydraulic step testing. Walton's classification, which gives an indication of how a well is performing, showed that the test well improved from "severely clogged" to "properly designed" once development was complete. The calculated well efficiency at an equivalent pumping rate for each test increased from 71 to 95 percent during development.

Table 2. Test well performance indicators derived from hydraulic testing.

Hours into cable tool development	Walton's Classification	Well efficiency
5	Severely clogged	71 %
24	Mild deterioration	92 %
33	Properly designed	95 %

From the long-term hydraulic analysis, PW11 was determined to be over 90 percent efficient with a negligible drawdown radius of approximately 1 km.

In the end, we had a productive well that was capable of yielding water that met the anticipated target. The challenging geological setting provided some interesting obstacles that were ultimately overcome, thereby avoiding the costs of abandoning this location and drilling an entirely new test well.

6 DISCUSSION

The Shubenacadie-Milford Aquifer Complex, consisting of confined sand and gravel channels and more recent glaciofluvial channels, has historically proven difficult to exploit. This most recent pumping test suggests that adequate groundwater is indeed available for extraction to meet the Municipality's target. A horizontal collapse of the lower well screen during well construction provided the latest challenge to developing this resource.

When a catastrophic failure occurs at any phase of a project, it has the potential to wreak havoc on budget and schedule, and it can lead to unease about the project's status and future direction. In this case, an evaluation was made to determine whether to abandon this test well and start in a different location, or to create a plan to repair and rehabilitate the well screen. Ultimately, it was decided to continue developing the groundwater resource at this test well. This presented several challenges that had to be overcome, including designing the proper apparatus to repair the screen, obtaining a reasonable level of confidence that the screen would not fail again after rehabilitation and ensuring the buy-in of all stakeholders, including our client who represented the end users of the water supply.

Actual physical repair of the well screen was accomplished reasonably quickly in the field, within approximately 30 minutes, and from there the project required patience and diligence as we completed the slow process of gently developing the test well through the repaired screen interval. Despite all this effort, the well screen was not completely restored back to normal – it remains partially collapsed with an effective opening equal to 2/3 the original diametre and a few vertical support rods became dislodged in the process. Of a total 44 rods, four were visibly impacted which leaves over 90 percent of the rods visibly intact. Continued monitoring of PW11 indicates that the screen has maintained its integrity to date and is hydraulically efficient.

A seven day constant rate hydraulic pumping test was completed in the repaired well at a rate of 150 igpm in July 2008. Overall aquifer transmissivity and storativity from the testing were determined to be in the range of 260 m^2/day and 1.1×10^{-3}, respectively (Stantec 2008), and are within the range of previously reported values in this aquifer. The well's performance during the test indicated that the lower screen functioned normally.

Rather than abandon the test well location when the lower screen failed, our team opted to rehabilitate the well and through persistence and a little ingenuity, the well was able to operate efficiently. This was important to the stakeholders given the historical difficulties encountered in this aquifer during previous attempts at exploiting the groundwater resource. By staying at this location instead of drilling a new test well, the Municipality was saved the cost of replacing the well, estimated to be between $30,000 and $40,000.

ACKNOWLEDGEMENTS

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