Sealing a Complex Flowing Well in the Manitoba Interlake: A Case Study of the Silver Flowing Well

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ABSTRACT
In 2003, a local water well driller in the Manitoba Interlake was contracted to undertake the installation of a127 mm diameter water well into the Carbonate aquifer for agricultural use. The driller and land owner were aware that the water levels in the Carbonate aquifer in the area were flowing artesian but believed the head was less than 1 m above ground surface. During the drilling of the well a shallow sand and gravel deposit, directly overlying the carbonate bedrock, was encountered, and the driller lost control of the borehole. Attempts to seal the well were unsuccessful and the hole was abandoned. The rate of flow from the abandoned well was more than 114 L/s, with an estimated head of about 6 m above surface. The borehole was left to flow to the nearby Icelandic River.

This paper presents an innovative method that was used to cement and seal the borehole without the use of de-pressurization wells to lower the head. The borehole was subsequently sealed and cemented using this method, with a useable well left in place.

RÉSUMÉ
En 2003, un perceur local de puits d'eau dans le Manitoba Interlake a été embauché pour entreprendre l'installation de millimètre de diamètre a127 puits d'eau dans la couche aquifère de carbonate pour l'usage agricole. Le perceur et le propriétaire de terre se rendaient compte que les niveaux d'eau dans la couche aquifère de carbonate dans le secteur aient été écoulement artésien mais cru la tête était moins de 1 m au-dessus de la surface de la terre. Pendant le forage du puits un gisement peu profond de sable et de gravier, recouvrant directement la roche en place de carbonate, a été produit, et la foreuse a perdu la commande du forage. Les tentatives de sceller le puits étaient non réussies et le trou a été abandonné. Le débit du puits abandonné était plus de 114 L/s, avec une tête prévue d'environ 6 m au-dessus de la surface. Le forage a été laissé pour couler dans le fleuve islandais voisin.

Ce document présente une méthode innovatrice qui a été employée pour cimenter et sceller le forage sans utilisation des puits de dépressurisation d'abaisser la tête. Le forage a été plus tard scellé et cimenté suivre cette méthode, avec une gauche bonne utilisable en place.

1 INTRODUCTION

The Interlake area of Manitoba is underlain by limestone and dolomite which forms a highly productive fresh water aquifer known as the Carbonate aquifer. Well yields typically exceed 5 L/s and some wells have been reported to produce as much as 150 L/s. Flowing wells are not uncommon in parts of the Interlake, particularly along the shores of Lakes Winnipeg and Manitoba where high static levels are associated with the regional discharge areas of the aquifer. Flowing artesian conditions are also found where low-permeability zones in the bedrock inhibit water movement from recharge to discharge areas or where linear bedrock depressions have been infilled with clays and tills.

In early 2003 a cattle farmer near Arborg in the Rural Municipality (RM) of Armstrong contracted with a local water well driller to install a 5 inch diameter PVC cased well in his pasture for use as a seasonal water supply. The driller advised the land owner that local water well records in Manitoba Water Stewardship's (MWS) GWDRILL database indicated that the static water level in the area was above surface and a pump would likely not be needed. The driller believed that the water level at the site would not exceed a meter above ground.

A drilling log was taken by the driller, which noted the following stratigraphy (GWDRILL, 2009):

- Ground level – 3 m below grade – Clay and stones
- 3 m to 6.1m below grade – Till with boulders
- 6.1 m below grade to 9.1 m below grade – Till with stones
- 9.1 m below grade to 11 m below grade – Till and gravel
- 11 m below grade to 11.6 m below grade – Fractured limestone

- 11.6 m below grade to 12.2 below grade – White fractured limestone

The driller had difficulty in seating the casing into the bedrock and attempted to cement a surface casing in the borehole in an attempt to control the flow from the borehole. At this point, the borehole was flowing significantly outside the 127 mm diameter casing. The driller tried various methods of cementing to seal the borehole without success. According to the log contained in GWDRILL, the driller placed over 300 bags of cement in the borehole prior to abandoning the well and pulling off the site. The log contained in GWDRILL is shown below as Figure 1.

Manitoba Water Stewardship
Water Branch
WELL INFORMATION REPORT

Manitoba

2008 Mar 14

LOCATION - NW20-21-2E
Owner - JOHNSON DAIRIES
Driller - Interlake Water Supply
Well Name - PASTURE WELL
Well Use - PRODUCTION
Well Status - ACTIVE
Date Completed - 2003 May 13 Aquifer - LIMESTONE OR DOLOMITE
Top of Casing - 12.0 ft. above ground
Remarks:
TRIED TO CONTROL FLOW IN 8". EXTENDED 5" TO 21' ABOVE GROUND
TO OVERCOME INSIDE FLOW. TRIED PRESSURE GROUTING, DID NOT WORK,
WASTED 300 BAGS OF CEMENT, WELL LEFT FLOWING OUTSIDE 8" INTO
DITCH. WELL OUT OF CONTROL. SEALED OFF INSIDE FLOW BUT NOT
OUTSIDE - MAIN WATER COMING FROM 36'-38'.

WELL LOG (Imperial units)

From	To(ft.)	Log
0.0	10	CLAY AND STONES
10.0	20	TILL WITH BOULDERS
20.0	30	TILL AND STONES
30.0	36	TILL AND GRAVEL
36.0	38	FRACTURED LIMESTONE
38.0	40	WHITE FRACTURED LIMESTONE

WELL CONSTRUCTION

From	To(ft)	Casing	Inside Dia.(in)	Outside Dia.(in)	Slot Size(in)	Type	Material
0.0	40.0	CASING	5.0	9.6			PVC
0.0	20.0	CASING	8.0				PVC

PUMPING TEST
Date : 2003 May 16 Flowing 492.0 Imp. gallons/minute
Water level before test : 12.0 ft above ground
Water level at end of test :
Test duration: Water temperature: degree(s) F
Test duration: Water temperature: degree(s) F

WATER USE
Livestock

Figure 1 – Borehole log – GWDRILL, 2003

Sometime following the abandonment of the borehole, the land owner connected a small saddle and valve to the well to allow for continuous watering of his nearby animal trough. A small trench was dug to the ditch on the north side of the property, to allow the water to flow to the provincial drain system, and ultimately to the Icelandic River. The well as it was left is shown below as Figure 2.

Figure 2 – Silver flowing well (source – MWS, 2007)

The Province of Manitoba and the RM of Armstrong expressed a desire to have the well properly capped and sealed. The province visited the site and measured the flow in the channel to be approximately 37 L/s. The province developed a request for proposal to seal the well.

2 METHODOLOGY FOR CONTROLLING FLOW IN THE BOREHOLE

The methodology for sealing the borehole was developed by Friesen Drillers Limited, of Steinbach, Manitoba. A crew mobilized to the site in March, 2007, with a dual rotary casing advancement drill rig, picker truck, and water/service truck. Prior to arrival of the equipment, the land owner arranged for the removal of the watering troughs and piping near the well, and undertook snow clearing at the site.

Upon arrival at the site, the hoses and discharge saddle were removed from the 203 mm diameter PVC casing. The 203 mm and 127 mm casings were cut down to within one foot of grade. In order to allow for access, 100 mm crushed limestone was delivered to the site and placed around the well. In addition to the gravel, a substantial amount of ice was broken up and hauled away to allow the rig to set up on a firm working surface.

Following the rig set up and levelling, the casing advancement method was used to advance 6.4 m of 406 mm casing overtop of the existing PVC casing. It should be noted that the 406 mm diameter casing was equipped with a 406 mm diameter casing drilling shoe, equipped with carbide cutting buttons. A 381 mm diameter tricone roller bit was used to drill out the casing/cement/gravel from the center of the borehole. Cuttings were lifted to surface using the drill rig's service air compressor. During drilling, a substantial amount of 127 mm and 203 mm diameter PVC cuttings, cement, and some large stones and clay were ejected from the rig discharge.

The casing was set to a level of approximately 5.5 m below grade, with approximately 1 m of stick up. A photo showing the casing installation is shown below as Figure 3. With the service air blowing the well, the head was noticed to drop, which showed a good seal between the 406 mm diameter surface casing and the upper clays/tills. With the service air shut down and the drill rod/bits removed, water flowed overtop of the 406 mm casing to a level of approximately 76.2 mm above the top of the pipe. Using equation #1 for 406 mm pipe revealed a flow rate of approximately 145 L/s (Anderson, 1971, pg.155).

Equation #1 $Q = 5.68 \times C \times D^2 \times H^{1/2}$

Where:

C = Constant (0.87 to 0.92) - Steel ERW casing = 0.92
D = Diameter (406 mm)
H = Height (76.2 mm above top of pipe)

Figure 3 – 16 inch diameter casing installation (source – MWS, 2007)

Following the calculation of the flow from the 406 mm diameter casing, two lengths of 305 mm diameter steel casing was drilled into the well using the casing advancement method. It was anticipated that the casing would be seated into the bedrock noted at 11.6 m below grade in the construction log. However, during the drilling of the 305 mm casing, competent bedrock was not noted at that depth. It was assumed that substantial wash out may have occurred at the casing socket area due to the mud rotary method of the original borehole, and the length of time the borehole had been allowed to flow. In order to hold the 305 mm diameter casing in place, lifting lugs were welded to the 305 mm casing to provide additional support.

Once the 305 mm casing was fully installed, 152 mm diameter threaded and coupled pipe was installed to a depth of 11 m. The pipe was equipped with an air line fitting at the bottom to allow for air line pumping with the service compressor of the rig. Using his method, water was able to be pumped from the well at a rate of approximately 160 L/s. At this flow rate, water was just flowing over the top of the 406 mm casing. Several 50 mm diameter suction hoses were then installed in the 305 mm well to allow for water to be siphoned off and discharged on the ground nearby. These two methods were able to maintain the head below the top of the 406 mm diameter steel casing.

The final pumping arrangement is shown below in the following photograph as Figure 4.

Figure 4 – Final pumping arrangement (source – MWS, 2007)

3 PREPARATION FOR SEALING

Immediately after the flow in the borehole was controlled as best as possible, preparations were made for sealing the borehole. In order to seal the annulus between the 305 mm diameter steel casing and the fractured carbonate bedrock, bentonite hole plug was added between the 305 mm casing and 406 mm casing. Several bags of hole plug were added before a tag line was noted to measure the material rising on the outside of the 305 mm casing. Following an hour of set up time, sand was added on top of the bentonite. The seal was placed to attempt to prevent cement from circulating through the fractured rock and into the 305 mm diameter well. Throughout the process, the well was continued to be pumped through air lift pumping and siphoning to maintain the lowered head conditions.

4 CEMENTING THE BOREHOLE

Prior to arriving at the site, a cement grout mixture was determined from Anderson, 1971. The design mix for the cement called for approximately 17 L of water per 40 kg sack of cement. This mix was determined to have an approximate weight of 1440 kg/m^3 prior to setting, and 2000 kg/m^3 once fully cured after 28 days. The weight of this mix was determined to have enough mass to overcome the approximate 6-7.5 m head in the borehole.
Prior to ordering the cement mixture, unit weights were calculated ahead of time using a sample mix design on a

mud balance, which is shown below as Figure 5. The balance was used to determine if the mix design would be acceptable for the weighting material.

Figure 5 – Mud balance (source – author)

It should be noted that absolutely no bentonite or other additives were included in the cement mix, as these additives would likely reduce the weight of the material. Based on purely mathematical calculations, approximately 25 bags of cement would be required to seal the space between the 305 mm and 406 mm diameter steel casing. Since it was known that some amount of cement would extend into the gravel and fractured rock overlying the carbonate bedrock, and a large washout appeared to exist at the near the bedrock contact, the volume of cement required was tripled.

The cement was pumped into the well using a high pressure pneumatic grout through a 25 mm diameter grout line placed between the 305 mm and 406 mm diameter casings. The grout line was extended to a depth of approximately 10.6 m below grade. During the cementing the air line pumping system and siphoning lines were operated to maintain the lowered head conditions in the well. Cement was noted to rise on the outside of the 406 mm diameter casing. During the grouting procedure, cement was noted to discharge from the 305 mm well during the air lift pumping, although the discharge did indeed clean up immediately afterwards. After approximately 75 bags of cement were pumped into the well before water discharge was noted in the space between the 305 mm and 406 mm diameter steel casings. In total, approximately 100 bags of cement were utilized in the grouting procedure on the well.

Due to the sensitivity of the installation of the 406 mm diameter steel casing, it was decided that leaving the casing in place after the grouting operation would offer the most protection for the newly placed grout seal. Since a substantial amount of the cement came out at surface on the outer side of the 406 mm diameter casing, it can be assumed that the casing is firmly cemented in place to the surrounding geology. Figure 6, shown below details the cementing process.

Figure 6 – Cementing process (source – MWS, 2007)

5 CAPPING

Following the completion of the grouting procedure, the cement was allowed to set for approximately one hour prior to shutting off the air lift pumping. The borehole was then allowed to flow for several days prior to installing the permanent borehole cap.

The borehole cap was installed by welding a flange ring to the 305 mm diameter steel casing, with a valve installed in the top cap plate. In order to weld on the flange, the head in the well was lowered using an 8.5 m^3/min compressor and several siphon hoses. The borehole cap was then placed and the head was determined to be approximately 5.5 m above grade in the well. All flow was noted to be sealed from the outside of the casing in the well.

6 DISCUSSIONS

This project stresses the importance of selecting the correct drilling technique for the geological and hydrogeological conditions. Careful planning combined with proper cementing techniques are required to avoid loosing control of the borehole during drilling operations.

The casing advancement method allowed for the over drilling of the failed casing installation. This method provided the ability to lower head conditions suitably to allow for effective cementing.

ACKNOWLEDGEMENTS

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REFERENCES

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