Rehabilitation and Development of Well 3-93 and Well 7-00

For:

Clearbrook Waterworks District

2564 Clearbrook Road

Abbotsford, BC

By:

GW Solutions Inc.

August 2008

Table of Contents

Summary

Between April 13 and May 3, 2008 well rehabilitation and development efforts were undertaken for Wells 7-00 and 3-93 of the Clearbrook Waterworks District (CWD). GW Solutions Inc. worked with Fyfe Well & Water Services (Fyfe) and Kleinfelder Inc. (Kleinfelder). Well rehabilitation efforts included video inspection, pumping, brushing, bailing, Hydropuls ®, air-lifting, surge pumping and rawhiding. Work also included replacement of the riser pipes with stainless steel pipes and the installation of an additional check valve, and new submersible pump cables. Pre and post rehabilitation pumping step tests were conducted to assess the specific capacity of the wells. The rehabilitation process removed volumes of fine sediment, mineral encrustation and dislodged organic materials from the screen surfaces and from within the aquifer matrix for both wells. The greatest removal rate was achieved by using the Hydropulse ® technology. Video-inspection confirmed that for Well 3-93 a section of the stainless steel screen is damaged, and a part of the well casing is out of alignment. This damage may result in sediment entering the well and CWD water supply system. Well 7-00 casing and screen section did not show any signs of structural damage. For both wells the pump and motor are in good working condition. Unfortunately, the rehabilitation efforts did not improve the production rate of Wells 3-93 and 7-00. Post rehabilitation mini pump test for Well 3-93 showed a decrease in specific capacity. Similarly, the detailed step test for Well 7-00 showed a reduction in specific capacity after rehabilitation. Such a response to well rehabilitation is a surprise. This could be related to the removal of fines near the screen accompanied by a transfer of fines without removal in the aquifer matrix further away from the screen. This could also be partially related to the clogging of the aquifer with micro bubbles of gases realeased during rehabilitation. Monitoring well performance over time should reveal whether well production will improve over time or whether further actions are required to improve the operation of both wells.

1. Background

Between April 13, 2008 and May 3, 2008, GW Solutions, Inc. worked with Fyfe Well & Water Services (Fyfe), Kleinfelder Inc. (Kleinfelder), and Clearbrook Waterworks District (CWD) staff on a comprehensive redevelopment of CWD Wells 3-93 and 7-00. Wells 3-93 and 7-00 are in operation since 1993 and 2000, respectively.

Development is a very important part of well completion. It consists, after installation of the well screen, in applying various mechanical or hydraulic methods to remove fines near the well screen and in the aquifer near the well to open the pores of the aquifer and promote the movement of groundwater towards the well. The development historically completed on both wells has been only limited to the development carried out after the initial construction of the wells. There is no detail of the development completed. The report for Well 7-00 states that “the well was developed by air-surging until the amount of sand that could be drawn through the well screen was reduced to an acceptable amount”.

Development needs to be conducted on wells on a regular basis, and is then referred to as re-development or well rehabilitation. It is conducted to remove encrustation and bacterial growth on and near the screen and to remove fines and bacterial growth in the aquifer near the screen, thus reopening the pores in the aquifer and facilitating the movement of groundwater.[1]

The main scope of the well rehabilitation and development work for CWD was to (i) provide an assessment of the functioning and (internal) condition of the wells; (ii) cleaning of the well screen and removal of deposits from the well sump; (iii) rehabilitation (removal of mineral and organic deposits, plugging particles) of the well screen and adjacent aquifer; and (iv) reconstruct selected parts of the well (riser pipes, check valves, pump cables).

In addition, Fyfe assisted CWD in removing the pump assembly from Well 6-59. This well will later be converted to a monitoring well and potentially an emergency manual production well. Details of this work are presented in Fyfe's report.

Because of the different parties involved in the rehabilitation and development efforts, the report has become a joined effort between GW Solutions, Fyfe and Kleinfelder. The overall report is provided by GW Solutions. The main section of this report summarizes the methodology, results, conclusions and recommendations. Appendix A contains the report prepared by Fyfe, and Appendix B contains the report prepared by Kleinfelder.

2. Methodology

The following tasks were performed during this period (categorized by nature of the task and listed not in any particular order):

- **Rehabilitation**
  - Brush and bail;
  - Hydropuls ®;
  - Isolation airlifting; and
  - Surge pumping and removal of water and dislodged material.
- **Reconstruction / development**
  - Replace existing 6-inch riser pipes (steel drop pipes) with stainless steel pipes and couplings (both wells);
  - Add an additional check valve (both wells);
  - Installation of new submersible pump cable (both wells); and
  - Electrical assessment of the Franklin motor to assess the 'health' of the motor.

---

[1] Possible reasons for well rehabilitation are (Houben and Treskatis, 2007) (i) material deterioration (corrosion) of casing, screen, pump, pipes, and annular filling; (ii) buildup of mineral incrustation; (iii) biomass accumulation (biofouling); (iv) particle mobilization (sand intake) and particle accumulation (mechanical clogging); and (v) ground movement (soil settlement, earthquakes).

- **Pump tests**
    - Detailed pre (Well 3-93 and 7-00) and post rehabilitation (Well 7-00) pump step tests to determine the specific capacity of each of the wells; and
    - Mini pump tests to determine interim specific capacity values.
- **Well sanitizing and water quality sampling & analysis**
    - BART (biological activity reaction test) sampling and analyses;
    - Post development water sampling for bacteriological analyses;
    - Well disinfection; and
    - Flushing of residual chlorine from well.
- **Visualization**
    - Pre and post rehabilitation video inspection;
    - Creation of detailed well construction log; and
    - Documentation of pump installation details.
- **Other**
    - Fyfe assisted CDW in converting Well 6-59.

Several rehabilitation techniques were applied. Brushing is a technique whereby solidified incrustations are removed from the well interior (casing) by brushing (Figure 1). Brushing also removes the scales of the interior of the well screen. Brushing is often used as a preparative step before other rehabilitation techniques. Brushing is followed by bailing whereby repeated lowering, filling, raising and emptying of a bailer (cylindrical tube fitted with a valve at the bottom; based on a piston principle) fluid and debris are removed from a well (Figure 2).

Figure 1: Brushing of Well 3-93

Figure 2: Bailor used for removing debris from the wells.

Isolation airlifting refers to the process whereby a pipe is inserted into a well and forcing compressed air to the inside bottom of the pipe. The air forces movement of the water column upward in the well, thus creating a drawdown which drives groundwater from the aquifer towards the well, usually under high hydraulic gradient. Surge pumping refers to the repeatedly starting and stopping of a pump. Raw-hiding normally refers to the process of raising the water column (normally with air-lifting) and then suddenly stopping the air flow which allows the water column to fall back into the well and thereby create a 'surging' action (Fyfe 2008).

As described in Fyfe's report (Appendix A): "Hydropuls ® methodology is a patented impulse generation type technology that can effectively loosen and mobilize sediment, bio-growth and mineral incrustation both on the well screen and within the aquifer matrix. Hydrostatic pressure is used to bring loosened material into the well bore where the material can be removed from the well via pumping, airlifting or bailing". Kleinfelder report (appendix B) details the steps involved in using Hydropuls ® for the rehabilitation process.

Pumping (step) tests were performed to compute the specific capacity (Sc) of each of the wells. It is a well performance indicator. Sc is the ratio of the production rate or yield of a well to the drawdown required to produce that yield. The pumping step test requires monitoring the drawdown for different pumping rates for a fixed time interval.

The BART sampling and analyses were performed by CWD staff.

3. Results and Conclusions

3.1 Physical condition

Based on the work performed by Fyfe and Kleinfelder the following was observed (and actions taken) for Wells 3-93 and 7-00:

- Well 3-93
    - Casing is slightly corroded and casing joints are in good condition (Kleinfelder report).

  - The well shows a significant 'bend' in the casing beginning near the static water level. This causes strain on the well pump column and creates difficulty in sealing the water discharge at the pit-less adaptor spool assembly (Fyfe report).
  - Post-rehabilitation video inspection shows that the screen was in good condition with the exception of the damaged zone (Kleinfelder report).
  - The majority of the fine sediment on the horizontal wires of the screen has been removed along with the mineral encrustations (Kleinfelder report).
  - A section of the stainless steel screen is damaged (from depth 114.2 to 114.6 ft) (Kleinfelder report). This damage may result in sediment entering the well and CWD water supply system (Fyfe report).
  - The motor has seen some significant wear (considering the fact that it is only in operation for 3 years) (Fyfe report). The wear might have been a result of the soft start protocol/set-up.
  - The submersible pump cable showed significant signs of abrasion, and therefore was replaced (Fyfe report).
  - Because of significant corrosion of the steel drop pipes (riser pipes), these pipes were replaced with stainless steel pipes and couplings.

- Well 7-00
  - Casing is slightly corroded and casing joints appeared in good condition with no cracks or separation (Kleinfelder report).
  - Post-rehabilitation video inspection shows that the screen is in good condition (Kleinfelder report).
  - The majority of the fine sediment on the horizontal wires of the screen has been removed along with the mineral encrustations (Kleinfelder report).
  - The motor was found to be in very good condition. There was no premature wear.
  - The submersible pump cable shows significant signs of abrasion, and therefore was replaced (Fyfe report)
  - Because of significant corrosion of the steel drop pipes (riser pipes), these pipes were replaced with stainless steel pipes and couplings.

3.2 Well performance

One of the objectives of well rehabilitation is to improve well performance and the parameter used to quantify performance is specific capacity which is the yield divided by the drawdown and is expressed in l/s/m.

Figures 3 and 4 show the specific capacity for Well 3-93 and 7-00 respectively.

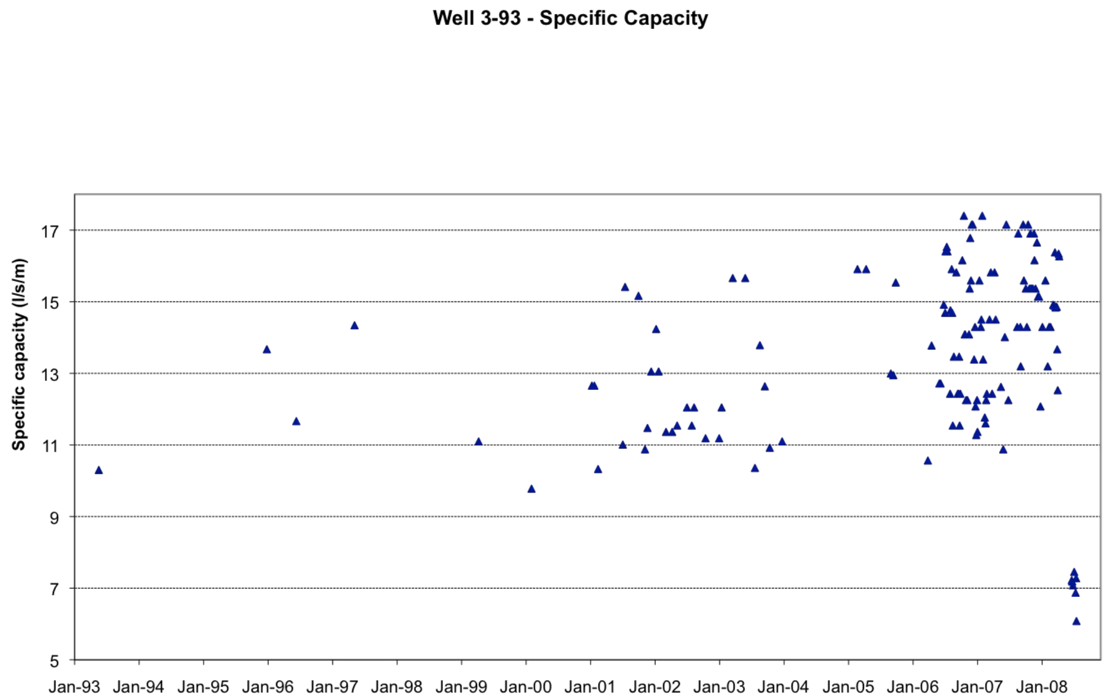

Figure 3: Specific capacity vs time - Well 3-93

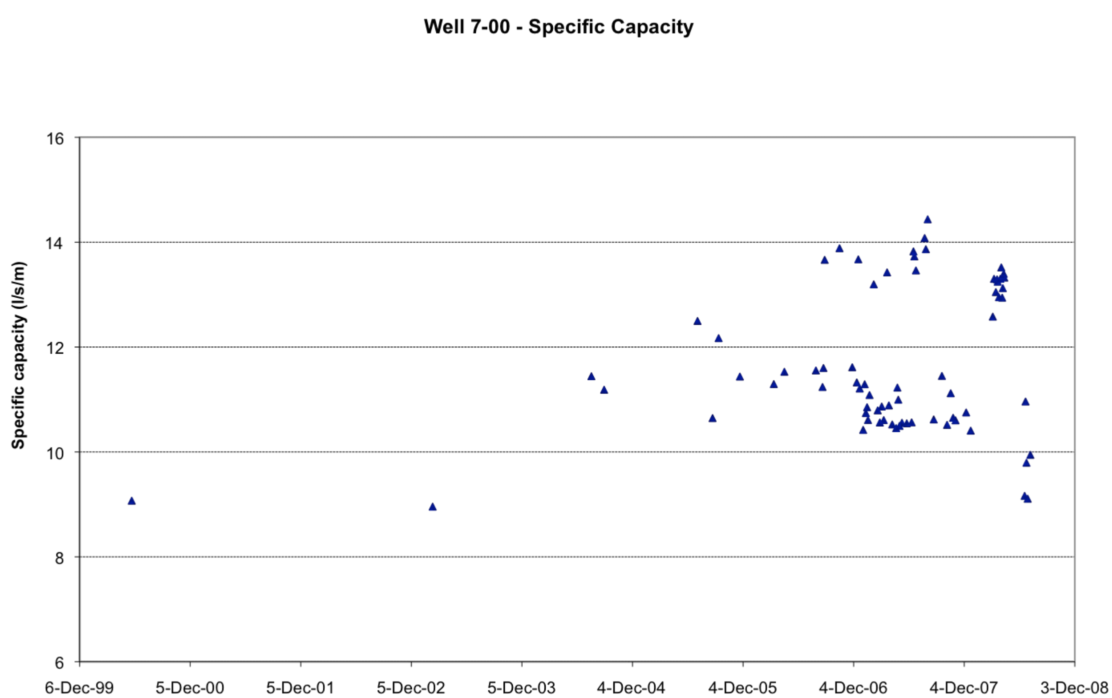

Figure 4: Specific capacity vs time - Well 7-00

Figure 3 shows that the initial specific capacity of Well 3-93 was reported to be 10.3 l/s/m immediately after construction of the well in 1993. Based on data recorded (pumping rates, depth to water at rest and when pumping), the specific capacity has ranged between 11 l/s/m and 17 l/s/m. After development, the specific capacity is calculated to range between 6 l/s/m and 7 l/s/m. We therefore observe a reduction in specific capacity when comparing the post-development values to the pre-development values.

Figure 4 shows that the initial specific capacity of Well 7-00 was reported to be 9.1 l/s/m immediately after construction of the well in 2000. Based on data recorded (pumping rates, depth to water at rest and when pumping), the specific capacity has ranged between 10 l/s/m and 14 l/s/m. After development, the specific capacity is calculated to range between 9 l/s/m and 11 l/s/m.

No trends in the variation of the specific capacity are identified for well 3-93 because the data appear as a cloud in Figure 3. However, for Well 7-00 (figure 4), there is an observed reduction in specific capacity versus time between 2004 and 2007. It also clearly shows two sets of data, one between 10 l/s/m and 12 l/s/m and the other between 13 l/s/m and 14 l/s/m. This corresponds to a difference in efficiency when Well 7-00 pumps at the same time as Well 3-93 or when it is the only producing well. When pumping with Well 3-93, the discharge rate is lower and the drawdown is greater, resulting in a lower specific capacity.

Another way of assessing the behaviour of wells is to perform short pumping test with increments of pumping rates. These tests are called “step tests”. Typically, energy losses through the aquifer and through the well screens are functions of the groundwater velocity near the well, and step tests can provide additional information on wells, screen and aquifer dynamics.

Figures 5 though 7 and Table 1 summarize the results of the step tests, performed before (Wells 3-93 and 7-00) and after rehabilitation (Well 7-00). Figure 5 illustrates how pumping in Well 3-93 causes drawdown in Wells 7-00 and 6-59. Drawdown in Well 3-93 ranges between 1.92 m and 4.16 m (based on data logger information). Drawdown ranges between 0.37 m – 0.88 m and 0.41 m – 0.92 m for Wells 6-59 and 7-00, respectively. A drawdown of about 9 cm was observed in Well 1-87.

Figure 6 shows the increase of drawdown in Well 7-00 with the increase of pumping rates. In a similar way, drawdowns were recorded in wells 1-87, 3-93 and 6-59. Figure 7 shows the observed drawdowns in Well 7-00, after rehabilitation and the difference compared to the observed drawdowns in well 7-00 before rehabilitation, as indicated by the double arrows. The difference is in the order of 1 m.

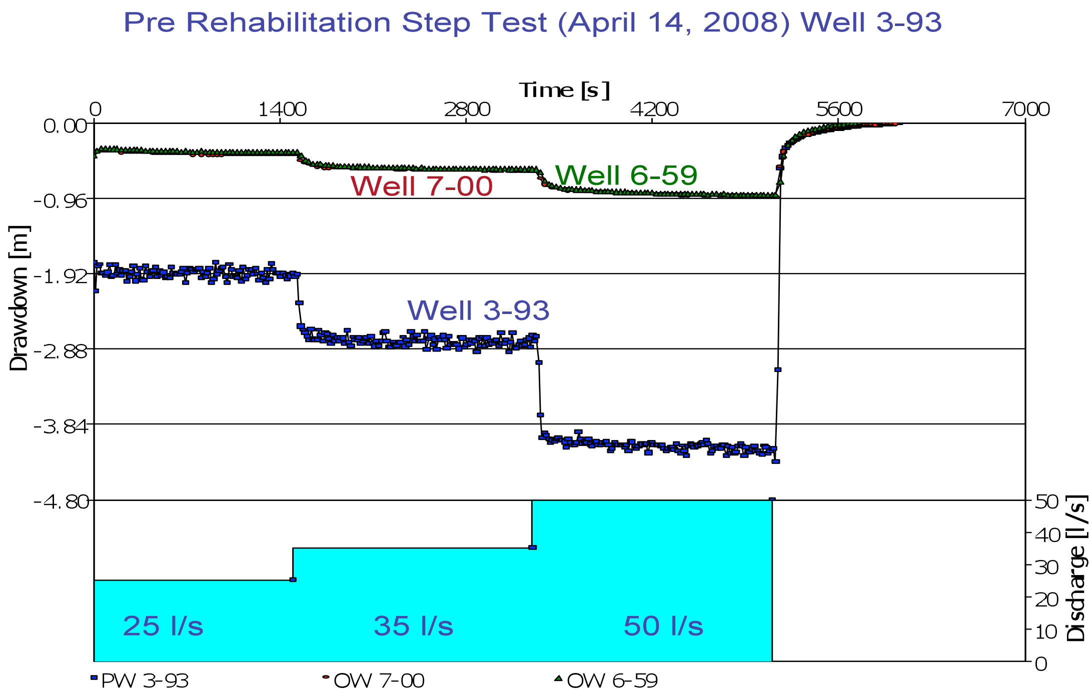

Figure 5: Pre-rehabilitation step test - Well 3-93

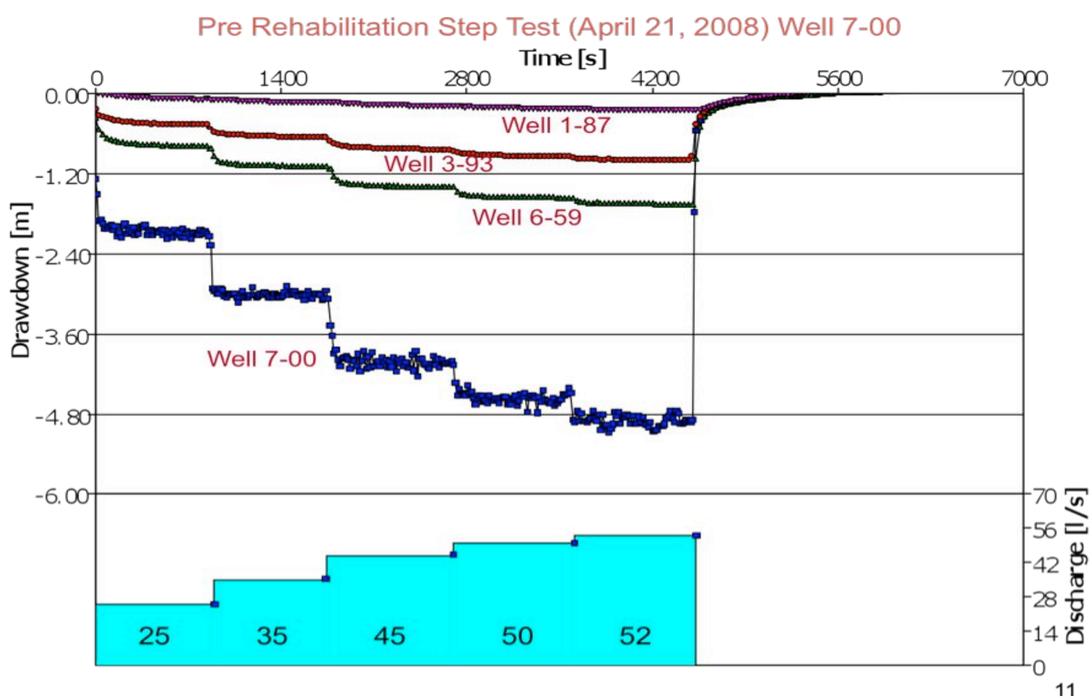

Figure 6: Pre-rehabilitation step test - Well 7-00

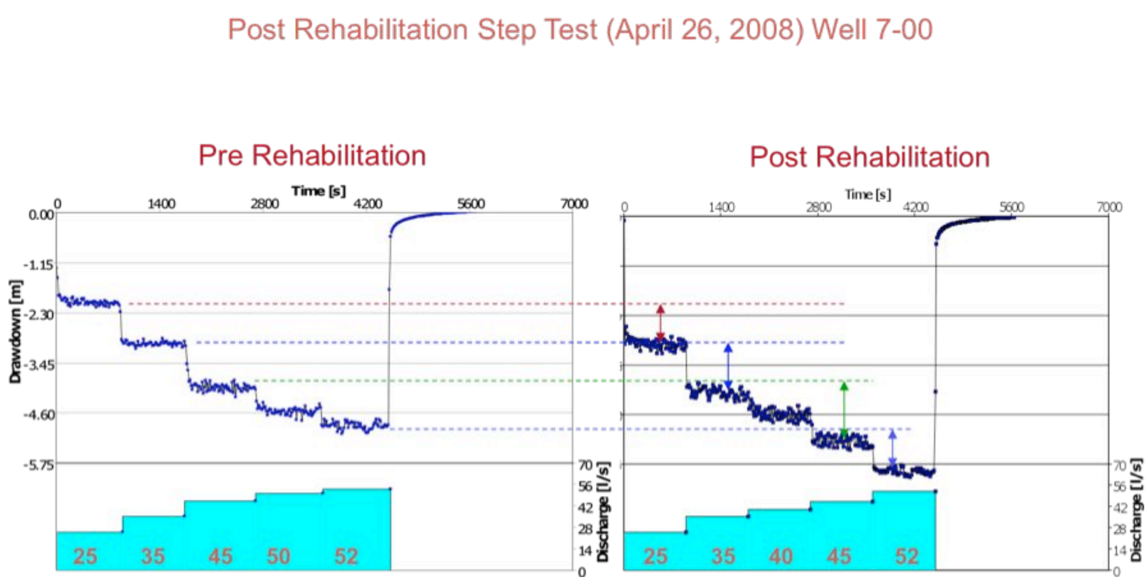

Figure 7: Comparison pre and post-rehabilitation drawdowns - Well 7-00

Table 1. Pumping step test results

				Data logger				Measure tape			
Well index no.	Pre / Post	Date	Discharge	Static level	Water level	Drawdown	Specific Capacity (S_c)	Static level (depth)	Depth to water	Drawdown	Specific Capacity (S_c)
		(dd-mm-yy)	(l/s)	(m)	(m)	(m)	(l/s/m)	(m)		(m)	(l/s/m)
3-93	Pre	14-Apr-08	25	11.2230	9.3076	-1.9154	**13.0518**	19.0774	20.7599	-1.6825	**14.8589**
3-93	Pre	14-Apr-08	35	11.2230	8.3692	-2.8539	**12.2641**	19.0774	21.7719	-2.6944	**12.9898**
3-93	Pre	14-Apr-08	50	11.2230	7.0670	-4.1560	**12.0308**	19.0774	23.3904	-4.3129	**11.5931**
3-93	Post	---	---	---	---	---	---	---	---	---	---
3-93	Post	---	---	---	---	---	---	---	---	---	---
3-93	Post	---	---	---	---	---	---	---	---	---	---
7-00	Pre	21-Apr-08	24.72	8.1506	5.9518	-2.1988	**11.2425**	19.2359	20.6441	-1.4082	**17.5546**
7-00	Pre	21-Apr-08	35	8.1506	5.2814	-2.8692	**12.1985**	19.2359	22.1925	-2.9566	**11.8381**
7-00	Pre	21-Apr-08	45	8.1506	4.2072	-3.9434	**11.4115**	19.2359	23.2166	-3.9807	**11.3046**
7-00	Pre	21-Apr-08	50	8.1506	3.7481	-4.4025	**11.3572**	19.2359	23.7622	-4.5263	**11.0466**
7-00	Pre	21-Apr-08	52.9	8.1506	3.3469	-4.8037	**11.0123**	19.2359	24.0670	-4.8311	**10.9499**
7-00	Post	26-Apr-08	25	8.3255	5.3856	-2.9399	**8.5105**	19.1414	22.0980	-2.9566	**8.4625**
7-00	Post	26-Apr-08	35	8.3255	4.2681	-4.0574	**8.6262**	19.1414	23.2197	-4.0782	**8.5822**
7-00	Post	26-Apr-08	40	8.3255	3.8770	-4.4485	**8.9918**	19.1414	23.7653	-4.6238	**8.6509**
7-00	Post	26-Apr-08	45	8.3255	3.2046	-5.1209	**8.7875**	19.1414	24.3596	-5.2182	**8.6237**
7-00	Post	26-Apr-08	52	8.3255	2.4428	-5.8827	**8.8395**	19.1414	25.0972	-5.9558	**8.7310**

An improvement in well performance was not observed for both wells as a result of the well rehabilitation efforts, contrary to what is typically observed during well rehabilitation and what was expected. Several explanations are proposed:

- The wells were not properly developed initially, after construction. The development energy applied during the rehabilitation in 2008 mobilized fine particles in the aquifers around the wells. These particles were not fully removed from the aquifer and are still trapped in the aquifer, reducing the opening of the pores.

- The aquifer is not homogeneous and contains thin layers or lenses of finer sand and silt. During the rehabilitation, some of these finer particles have migrated in the coarser sand layers, thus reducing their permeability.

- Gases (nitrogen, air) produced during rehabilitation when activating the hydropulse or developing with airlifting (isolation airlifting) are still trapped in the aquifer next to the screens. The gas micro bubbles may have partially clogged some pores, thus reducing the hydraulic conductivity of the aquifer. The introduction of these gases was not really preventable because 1) it is how the hydropulse operates and 2) the relatively short available water column does not provide the flexibility of generating large drawdowns (thus creating high hydraulic gradient which produce development) without having drawdowns within the screened zone.

3.3 Pre-rehabilitation BART results

Samples were collected from both wells prior to rehabilitation and submitted for Bacteriological Activity Reaction Tests (BART). Samples were collected at start-up and after 5 minutes of pumping to collect a water sample representative of the water present in the well at rest and in the aquifer at a short distance from the screen, respectively. The samples were collected in vials to provide information about the presence and level of aggressity of several types of bacteria:

- IRB: Iron related bacteria
- SRB: Sulfure reducing bacteria
- SLYM: Slime forming bacteria; and
- HAB: Heterotrophic (relying on organic source) aerobic bacteria

Once water is inserted in the vials, potential reactions are monitored for up to 8 days and observations are entered in an interpretation software. The results are presented in Appendix C.

Iron related bacteria and heterotrophic aerobic bacteria were identified in Well 3-93, for both samples. Slime forming bacteria were identified only in the “start-up” sample for Well 3-93. Sulfure reducing bacteria were not identified.

Analyzed bacteria were not detected in the start-up sample of Well 7-00. Iron related bacteria and heterotrophic aerobic bacteria were identified in Well 7-00, for the sample collected 5 minutes after start-up. Slime forming bacteria and sulfure reducing bacteria were not identified.

The BART analysis therefore indicated for Well 3-93 the presence of iron related and heterotrophic aerobic bacteria in the well, reacting with the casing and the aquifer in contact with the screen. The same bacteria are present farther away from the screen but their population is smaller and they are less aggressive.

The BART analyses for Well 7-00 indicated a relative “clean well”, however, iron related and heterotrophic aerobic bacteria were identified within the aquifer near the screen. They were similar and aggressively comparable to the bacterial population found near Well 3-93.

Post rehabilitation BART results were not available at the time of reporting.

3.4 Post rehabilitation microbiological analysis

Both wells were sanitized after rehabilitation and confirmatory water samples were submitted for bacteriological analyses required by Fraser Health (fecal coliforms and e.coli) prior to reconnection to the distribution system. The results confirmed that the water was potable.

3.5 Complicating factors

Well rehabilitation was conducted when CWD was in the process of upgrading monitoring to a SCADA system and changing the flow meters. Therefore there is discontinuity in the data set and it was also found that the flow meter installed in well 7-00 was providing erroneous information. The last reading with the old flow meter was recorded on February 28, 2008 with a value of 285 m^3/h. The first reading after installation of the new flow meter was recorded at 204 m^3/h (March 7, 2008). This represents a reduction of 39% in the flow rate. This has two consequences: The well was producing close to 40% less than estimated. The positive aspect is that the resulting assumed water consumption and demand is less than computed to date. Unfortunately it is not known how this error on the flow rate increased or drifted with time, and whether the flow meter was properly calibrated and operating when installed.

GW Solutions also compared the data provided by the pressure transducer that had been installed in Well 7-00 since start-up with both data provided by Fyfe’s data logger and to manual water level reading. The results indicate that the pressure transducer provided water column heights with an error of 13%. When the pressure transducer read a water column of 1 m, the actual water column was 1.13 m.

GW Solutions has revised the spreadsheet of Well 7-00 summarizing the flow meter and water levels data and adjusted the data, accordingly. GW Solutions has assumed that the difference originated from the time of installation and that it was constant over time.

Wells 3-93 and 7-00 were left without pressure transducers after rehabilitation as new pressure transducers were required for connection to the SCADA system. Therefore depths to water with or without pumping are not available for the period between April 14, 2008 and June 19, 2008.

Also, the diameter of the well screen is only 7 " (178 mm), instead of an assumed 8" (200 mm). Consequently, the entrance velocity of the wells is higher than originally assumed. A higher entrance velocity, mostly if it is greater than 3 cm/s is expected to be associated with the risks of creating turbulences. Non laminar flows generate additional head loss near the well screens.

4. Recommendations

Based on the work completed, observations made, and assumptions, GW Solutions makes the following recommendations:

- ✓ Collect data to compute specific capacity to assess the variation of the well performance and to monitor any improvement of the specific capacity with time.

- ✓ Complete additional well development using the airlifting and jetting methods. This development should be scheduled after investigation drilling for a new well, if this new well is located near Well 3-93 and 7-00. The investigation drilling will provide detailed information about the stratigraphy of the aquifer, in particular the presence of lenses of fine sand or silt.

- ✓ Improve the mobilization and movement of fines during development by using a biodegradable surfactant polymer.

- ✓ The existing pit surrounding Well 6-59 may pose a risk to the wellhead protection for Wells 3-93 and 7-00. The pit should be back-filled in conjunction with applying a surface seal to the area around the extended well casing (Fyfe report).

5. Acknowledgement

Fyfe Well & Water Services performed the day-to-day well rehabilitation field work, and well removal, reinstallation, and reconstruction work. Kleinfelder worked with Fyfe in applying Hydropulse ® technology and the video inspection. Fyfe and CWD staff assisted GW Solutions in performing the pumping tests. Quantitative water quality data was analyzed and provided by Bodycote in Surrey. BART sampling and analysis was performed by CWD staff. GW Solutions thanks CWD staff for their collaboration.

6. Closure

The assessment has been carried out in accordance with generally accepted engineering practice. No other warranty is made, either expressed or implied. Engineering judgment has been applied in developing conclusions and recommendations in this document.

This document was prepared by personnel with professional experience in hydrogeology. Reference should be made to the 'GW Solutions Inc. General Conditions and Limitations'.

GW Solutions was pleased to produce this document. If you have any questions, please do not hesitate to contact me.

Yours truly

GW Solutions, Inc.

Dr. Gilles Wendling, P.Eng., President

7. References

GW Solutions (2007), Hydrogeological Study, Report prepared for Clearbrook Waterworks District. 36 p.

Houben, G. and C. Treskatis (2007), Water well rehabilitation and reconstruction, McGraw Hill. 391 p.

Fyfe, J. (2008), personal communications.

Roscoe Moss Company, 1990, Handbook of Ground Water Development, John Wiley & Sons, 493 p.

Appendices

Appendix A: Report of Fyfe Well & Water Services

Appendix B: Report of Kleinfelder Inc.

Appendix C: BART Results

Appendix D: GW Solutions Inc. – General Conditions and Limitations