

3.0 SOUTH RIVERDALE AQUIFER

3.1 DRILLING PILOT HOLES TH1-08, TH2-08(A) AND TH2-08(B)

The City retained SDS Drilling of Calgary, Alberta to drill pilot holes for Wells 8 and 9 using a short stroke RDU sonic drill rig. The drilling locations were selected by the City and are shown in Figure 2. The locations of TH1-08, TH2-08(a) and TH2-08(b) were selected to coincide with the proposed locations for Well 9 and Well 8. TH2-08(b) was located about 1.5 m (5 ft) away from TH2-08(a) to provide sonic drill core for a section of lost recovery at TH2-08(a). Drilling supervision and core logging was conducted by Marc Andre Lavigne, EIT, of EBA.

3.1.1 TH1-08 (Pilot hole for Well 9)

Pilot hole TH1-08 was drilled at the Well 9 drilling site on August 12, 2008 to a depth of 32 m (105 ft) below ground level (bgl). The borehole log is included in Appendix A, and core photographs can be found on the photograph CD included with this report.

Soils encountered at TH1-08 consisted of a glaciofluvial succession of sorted sandy sediments with various silt and gravel content overlying sandy silt and till sediments at a depth of about 29 m (95 ft) bgl. The sandy silt and till sediments extend to a depth of approximately 31 m (101 ft) bgl and are underlain by basalt bedrock. The water table was encountered at approximately 4.4 m (14.5 ft) bgl.

The sequence of interbedded coarse sands and gravels from about 21 – 29.0 m is considered to be a confined or semi-confined aquifer (South Riverdale Aquifer) with a thickness of about 8.0 m.

3.1.2 TH2-08(a) and TH2-08(b) (Pilot holes for Well 8)

Pilot holes TH2-08(a) and (b) were drilled at the Well 8 drilling site on August 13, 2008 to a depth of 33.5 m (110 ft) and 29.0 m (95 ft) bgl, borehole logs are included in Appendix A, core photographs can be found on the photograph CD included with this report.

Soils encountered at TH2-08(a) and TH2-08(b) consisted of coarsening downward successions of sand and gravel to a depth of about 28.0 m (92 ft) overlying fine sand and silt. The silt and till sediments extend to a depth of about 32.3 (106 ft) bgl and are underlain by basalt bedrock. The water table was encountered at approximately 4.6 m bgs (15 ft).

The sequence of interbedded coarse sands and gravels from about 19 – 28.0 m is considered to be a confined or semi-confined aquifer (South Riverdale Aquifer) with a thickness of about 9.0 m.

3.1.3 Grain Size Analysis and Well Screen Design

Grain size analysis was completed with samples collected from pilot holes TH1-08 (pilot hole for Well 9) and TH2-08(a) and TH2-08(b) (pilot holes for Well 8) to assist with selecting the appropriate well screen opening size and placement interval. Sample depths are shown on the borehole logs in Appendix A, and grain size distribution curves are included in Appendix B.

For Well 8; grain size distribution analyses were completed on five samples from the following depths: 21.2 m (69.5 ft), 22.4 m (73.5 ft), 25.1 m (82 ft), 26.8 m (88 ft), and 27.6 m (90.5 ft). Based on the grain size results, 0.060" and 0.200" slot-size wire wound stainless steel telescoping screens were selected with a total screen length of 4.6 m (15 ft). The screen design also included about 1.1 m of riser pipe (3.5 ft) and a K-packer.

For Well 9; grain size distribution analyses were completed on six samples from the following depths: 20.4 m (67 ft), 21.9 m (72 ft), 23.8 m (78 ft), 26.5 m (87 ft), 27.0 m (88.5 ft), and 28.0 m (92 ft). Based on the grain size results, 0.060", 0.120", 0.150" and 0.020" slot-size wire wound stainless steel telescoping screens were selected with a total screen length of 7.0 m (23 ft). The screen design also included 0.9 m (3 ft) of riser pipe and a K-packer. In order to maximize the potential well yield for Well 9, the City asked EBA to increase the screen design capacity. EBA conveyed that the risks associated with an aggressive screen design could include ongoing sand production from the supply well, a requirement for extended well development time and possibly the risk of a failed well. After considering the potential risks, the City requested EBA to proceed with an aggressive screen design for Well 9.

Screen completion details are included as Figure 4 which provides construction details for Wells 8 and 9.

3.2 WELL 8 AND WELL 9 DRILLING AND CONSTRUCTION

Wells 8 and 9 were drilled from August 30 to October 8, 2008 by Encore Coring and Drilling Inc. (Encore) of Whitehorse, YT using a Schramm T450W air-rotary drill rig. Construction details are included as Figure 4. Plumbness and alignment testing was carried out prior to the screen installation by Icefield Tools Corporation of Whitehorse, Yukon working under sub-contract to Encore.

Well drilling, soil sample collection, alignment and plumbness, screen installation and well development were monitored by EBA personnel. Soil samples were obtained every 3 m (10 ft) while drilling through the unsaturated zone and the aquifer. However due to the highly disturbed nature of samples returned during air rotary drilling, the samples were used to confirm the expected ground conditions, but the screen design and screen placement interval was based on the samples collected during sonic drilling of the pilot holes.

3.2.1 Drilling, Construction and Development – Well 8 - 204110248

Drilling, construction and development of Well 8 was conducted by Encore from August 30 to September 8, 2008. Plumbness and alignment results are included as Appendix E. Following screen installation, Encore developed the well using a combination of air and water surging and jetting techniques. Turbidity and sand content was monitored throughout the well development process until there was no noticeable improvement in water clarity and sand content. Encore developed the well for a total of 35 hours, and the field measurement of turbidity at the end of well development was 15.7 NTU.

3.2.2 Drilling, Construction and Development – Well 9 - 204110249

Drilling, construction and development of Well 9 was conducted by Encore from September 8 to October 6, 2008. Two unsuccessful drilling attempts took place in August and early September. The first was due to a failed casing weld which became apparent during screen installation and the second was due to casing deviation, which exceeded the alignment criteria specified by the City. Plumbness and alignment results for the successful well are included as Appendix H. Immediately following screen installation, Encore observed large amounts of sand migrating through the well screen; and as a result, Encore was unable to advance the development tool to the bottom of the well screen. During development of the top portion of the well screen, a large volume of sand was being removed from the well and a sinkhole developed around the casing at ground surface resulting in stability problems for the drill rig.

After stabilizing the drill rig, Encore continued with well development which caused the well casing to migrate downwards (sink) and also caused the surface sinkhole to increase in size. EBA and Encore determined that the sand unit overlying the aquifer was migrating preferentially downwards into the screen and preventing a sand/gravel pack from developing around the well screen. This was likely due to a combination of an aggressive screen design, previous disturbance of the aquifer at this location during two failed drilling attempts, and potential differences in lithology between the pilot hole and final well location.

In order to stabilize the well casing and surface casing and to mitigate the downward sand migration into the well screen, pea gravel was used to backfill the surface sinkhole while continuing with well development. This development method was continued for 4 days until sand production stopped and water clarity began to improve. A total of 41 m³ of gravel was backfilled into the surface sinkhole. This value was approximately the same as the volume of sand removed from the well.

Once stable, well development continued using a combination of air and water surging and jetting for 3 additional days until the water clarity ceased to improve. Encore developed the well for a total of 69 hours, and the field measurement of turbidity at the end of well development was 5.98-NTU.

The large amounts of pea gravel backfilled around Well 9 could potentially have resulted in a vertical pathway for short circuiting of surface water to the aquifer. Ground Force Systems Inc. (Ground Force) of Abbotsford, BC was retained by the City to grout seal the backfilled gravel and effectively retrofit a sanitary surface seal. Ground Force tremie-grouted (from the bottom upwards) a surface seal around Well 9 from October 16 – 20, 2008. Grouting was completed by pressure grouting 20% solids bentonite grout around the casing through 1.25" tremie pipes installed at depths of 12.2, 6.1, 3.0 and 1.5 m (40, 20, 10 and 5 ft). Confirmatory pumping was conducted on October 24, 2008 by Aqua Tech to confirm there was no grout migration into the well screen interval.

3.3 HYDRAULIC TESTING AND WATER SAMPLE COLLECTION

Hydraulic testing with Wells 8 and 9 was completed by Aqua Tech working under contract to Ensign Drilling. Aqua Tech used a generator to power the pump, and water pumped from the well was discharged to a low lying area approximately 150 m from the well head. The flow rate was measured using a digital flow meter at the wellhead.

Water levels in the pumping well were monitored manually (using a graduated water level tape) and continuously using a Solinst Levelogger™. EBA also installed leveloggers in nearby observation wells TH5-04, TH4-04, and TH1-05 to provide a continuous record (2 min interval) of observation well water levels. A barometric logger was installed at surface to provide a record of barometric pressure during testing. Figure 5 shows a hydrograph of pumping and observation well water levels recorded during the pumping and recovery intervals.

3.3.1 Hydraulic Testing – Well 8

The step rate test with Well 8 was initiated on November 3, 2008 at 17:35. Four 60 min steps were conducted at flow rates of 12.9, 24.4, 37.7 and 44.4 L/sec (205, 387, 598, 704 USgpm). Recovery was monitored for 45 min until water levels had recovered to within 95% of the total observed drawdown. The maximum drawdown observed during the step rate test was 7.00 m. Drawdown and recovery observed during the step rate test is included in Appendix F1 and shown graphically on the upper portion of Figure G1 in Appendix G.

Based on water level observations made during the step-drawdown test and the pump capabilities a 72-hour constant rate pumping test was initiated on November 3, 2008 at 22:15 at a rate of 42.3 L/sec (670 USgpm). Upon termination of the pumping test, recovery was monitored manually for 11 hours and with the installed data logger for 11 hours. The maximum drawdown observed during the constant rate test was 6.74 m. Drawdown and recovery data for the constant rate test is included in Appendix F2 and shown graphically in Figure 6.

3.3.2 Hydraulic Testing – Well 9

The step rate test with Well 9 was initiated on November 7, 2008 at 15:45:36. Four 60 min steps were conducted at flow rates of 12.7, 25.4, 37.9 and 51.3 L/sec (201, 402, 600, 813 USgpm). Recovery was monitored for 16 min until water levels had recovered to within 95% of the total observed drawdown. The maximum drawdown observed during the step rate test was 1.91 m. Drawdown and recovery observed during the step rate test is included in Appendix I1 and shown graphically on the upper portion of Figure J1 in Appendix J.

Based on water level observations made during the step-drawdown test and the pump capabilities a 72-hour constant rate pumping test was initiated on November 7, 2008 at 20:00 at a rate of 47.3 L/sec (750 USgpm). Upon termination of the pumping test, recovery was monitored manually for 11 hours and with the installed data logger for 12 hours. The maximum drawdown observed during the constant rate test was 1.82 m. Drawdown and recovery data for the constant rate test is included in Appendix I2 and shown graphically in Figure 6.

3.3.3 Water Quality Testing (Wells 8 and 9)

EBA collected duplicate water samples from Well 8 on November 6 at 13:50 and from Well 9 on November 10 at 16:30. EBA collected the samples from a port at the wellhead in accordance with laboratory recommended procedures and in laboratory supplied sample bottles. Samples were transported on ice to Bodycote Testing Group in Surrey, BC (for detailed potability analysis) and to Yukon Environmental Health and Social Services Laboratory (for bacteriological analysis). Laboratory reports and certificates are included as Appendix K.

Field measurements of electrical conductivity (EC), pH, total dissolved solids (TDS), and turbidity were collected during the constant rate pumping tests with Wells 8 and 9. These results are included in Appendix F2 (Well 8) and Appendix I2 (Well 9).

3.4 DATA ANALYSIS AND RESULTS – SOUTH RIVERDALE AQUIFER

3.4.1 Well 8 Hydraulic Test Analysis

Drawdown observed during the step-drawdown test is plotted on the upper portion of Figure G1 (Appendix G). The lower portion of Figure G1 shows the specific capacity (L/s/m) and drawdown (m) vs. pumping rate (L/s) at the end of each step. The highest specific capacity was 7.9 L/s/m observed at the end of the first step flow rate of 13.1 L/s.

Drawdown observed in Well 8 during the constant rate pumping test is plotted on Figure G2. Also included on Figure G2 is residual drawdown vs. residual time factor (t/t^2)¹ observed during the recovery interval. A recharge boundary condition (flat-line) was observed around 3500 min into the pumping interval.

Data from nearby observation well TH4-04 was analyzed with AquiferTest analysis software using the Neumann and Walton (Hantush-Jacob) analysis methods. The interpreted transmissivity results from observation well data were on the order of 800 (Walton) - 1200 (Neumann) m^2/day with a corresponding hydraulic conductivity of 90 – 130 m/day .

Previous estimates of aquifer hydraulic properties report transmissivity of the aquifer ranging from 500 – 10 000 m^2/day with the corresponding conductivity ranging from 35 – 400 m/day (GLL 2005).

3.4.2 Well 9 Hydraulic Test Analysis

Drawdown observed during the step-drawdown test is plotted on the upper portion of Figure J1 (Appendix J). The lower portion of Figure J1 shows the specific capacity ($\text{L}/\text{s}/\text{m}$) and drawdown (m) vs. pumping rate (L/s) at the end of each step. The highest specific capacity was 29.5 $\text{L}/\text{s}/\text{m}$ observed at the end of the second step flow rate of 25.4 L/s .

Drawdown observed in Well 9 during the constant rate pumping test is plotted on Figure J2. Also included on Figure J2 is residual drawdown vs. residual time factor $(t/t')^2$ observed during the recovery interval. A possible recharge boundary condition (flat-line) was observed around 3000 min into the pumping interval.

Data from nearby observation well TH5-04 was analyzed with AquiferTest analysis software using the Walton (Hantush-Jacob) and Neumann analysis methods. The interpreted transmissivity results from observation well data were on the order of 550 (Walton) – 1200 (Neumann) m^2/day with a corresponding hydraulic conductivity of 70 – 150 m/day .

Previous estimates of aquifer hydraulic properties report transmissivity of the aquifer ranging from 500 – 10 000 m^2/day with the corresponding conductivity ranging from 35 – 400 m/day (GLL 2005).