Memorandum

GROUNDWATER SCIENCES CORPORATION

To: fYNOP File

From: Katlin Fleming, Staff Geological Scientist

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Re: Vertical Extent Well Construction Narrative

The vertical extent drilling was completed in two rounds which included drilling, construction, development, surveying and installation of dedicated sampling pumps or multiport samplers in each of the new deep wells.

1.1 Round One Vertical Extent Drilling

The six vertical extent wells MW-136A through MW-141A were installed during a six-month period from July 2012 to January 2013. Changes and additions to the FSP described in Addendums #1 (GSC, 2012d) and #5 (GSC, 2012f) include the modified drilling methods that were necessary to address the stacked solution openings penetrated by the borings. These methods include continuous casing advancement (CCA) using the Stradex system, and telescoping tubing with depth to seal off potential cross contamination from water bearing zones above. Drilling proceeded from one study area to the next study while groundwater samples from the first wells were analyzed by a laboratory. All drilling tasks were performed by Eichelbergers, Inc., under the supervision of a GSC geologist.

1.1.1 SW-WPL – MW-136A

The first phase of vertical extent drilling began in the SW-WPL at location MW-136A. Drilling and construction for this phase was conducted from June to July of 2012. To begin, a 16-inch diameter steel casing for stabilization of the unconsolidated residual soils above bedrock was placed in the top 21 feet of the borehole. Beyond 21 feet, 12-inch diameter Stradex continuous casing advancement (CCA) was used to complete the first phase of the borehole. The 12-inch CCA penetrated a sediment-filled solution cavity from 172-180 feet bgs which produced a blown yield of about 250 gpm. Weathered, fractured limestone continued below this solution cavity to the bottom of the borehole at 202 feet bgs. During drilling advancement from 180 to 202 feet bgs, a borehole water yield of about 50 gpm was observed, since the advancing casing partially impeded groundwater flow from the solution cavity.

At the time of drilling MW-136A, sinkholes and ground subsidence were observed on the west side of the Norfolk Southern railroad tracks. The potential for additional sinkhole development and/or ground subsidence created potential hazards to existing utilities, structures, drilling equipment and personnel. Daily inspections were performed around the drill rig and surrounding areas to look for evidence of ground subsidence. Any indication of movement was reported to the team and work was put on hold until the areas of concern were addressed.

While photoionization detector (PID) readings were elevated to 220 parts per million (ppm) in the borehole and in the containment vessel at 195 feet bgs, readings spiked to 1050 ppm in the void and fractured zone beginning at 202 feet bgs. This suggested the fractures are the source of the highest concentration of contaminants. Drilling at MW-136A was suspended due to the high PID readings in the breathing zone (89.9 ppm) and the drill crew moved to the first phase of drilling at

MW-139A while the personal protective equipment (PPE) and drilling methods to continue MW-136A were further assessed.

A water sample was taken from the bottom of the hole at MW-136A and analyzed for CVOCs prior to the continued advancement of MW-136A. From December 3, 2012 to January 8, 2013, drilling proceeded with Level B protection. During this time, the drilling process ran into difficulties re-engaging the drive shoe at the bottom of the well. After re-engagement was not successful, a cable tool rig was brought in to break through the shoe and continue to advance the borehole.

Water rotary was used to advance a 10 5/8-inch borehole to 220 feet and 8 5/8-inch steel casing was set in solid rock. Grout was pumped inside the casing and the casing was then lifted to allow grout to move to the outside of the casing. The grout seal on the 8 5/8-inch casing was tested after 17 hours and was found to be successful, with only 18 inches of water collecting inside the casing. This was carefully verified to assure that the highly concentrated groundwater penetrated above 220 feet had been successfully isolated. Advancement then continued with an 8-inch air rotary borehole to 270 feet bgs where a 5-inch steel casing was grouted in place.

The final advancement for the first phase of drilling to 320 feet bgs was achieved with a 5-inch open rock bore hole using air rotary methods. This open rock construction well was developed on January 8, 2013 to establish proper hydraulic connection with the surrounding aquifer and the groundwater was then sampled again and analyzed for CVOCs after a two week stabilization period.

1.1.2 NBldg4 – MW-139A

The first phase of drilling for MW-139A in the NBldg4 area took place between July 11 and August 1, 2012. Drilling with 15-inch air rotary methods was performed on the top of the hole to 83 feet bgs where 12-inch steel casing was set. The boring penetrated a sediment-filled solution cavity at 82 feet to 105 feet bgs which yielded approximately 150 gpm. To avoid the production of large volumes of water that were difficult to contain and manage, a 12-inch hole was advanced from 105 feet to 120 feet bgs using mud rotary methods, where 10-inch steel casing was set, and then again to 270 feet bgs where 6-inch steel casing was set. The 6-inch steel casing was grouted in place to the surface. The first phase of drilling at MW-139A was completed by drilling a 6-inch borehole from 270 feet to 320 feet bgs using air rotary methods. Only small water bearing fractures were encountered below 240 feet bgs. The well was developed on August 27, 2012 to establish proper hydraulic connection with the surrounding aquifer and the groundwater was then sampled and analyzed for CVOCs after a two week stabilization period.

1.1.3 TCA Tank/Building 2 Degreaser Area – MW-137A

MW-137A in the TCA Tank/Building 2 Degreaser area was drilled from August 17, 2012 to September 13, 2012. Prior to the drilling and completion of the first phase of drilling at MW-137A, drilling began at MW-137X, but large diameter 16-inch casing in MW-137X did not advance properly due to the presence of solution cavities and rock protrusions which caused the piping to become crooked. The piping was later removed and the hole properly abandoned.

Drilling of MW-137A advanced with first setting 24-inch steel casing to 5 feet bgs for stabilization of the unconsolidated material. This casing was later removed. The hole was advanced using 18-inch CCA Stradex drilling methods to 141 feet bgs. Air rotary methods were then used to drill a 15-inch hole and set 12-inch steel casing to 200 feet bgs. The 12-inch casing was grouted in place and then a 10-inch air rotary borehole was drilled to accommodate 6-inch steel casing to 270 feet bgs. The 6-inch steel casing was also tremie-grouted in place. Air rotary methods were used to drill a 6-inch borehole to bring the well to 298.5 feet bgs, its final depth for the first phase of drilling, and a temporary polyvinyl chloride (PVC) well was placed in MW-137A until further advancement in phase 2. Drilling was stopped short of the goal of 320 feet bgs because a clayand gravel-filled void was penetrated from 285 feet to 296 feet, and the drilling process, which was producing approximately 600 gpm, overwhelmed the containment equipment.

Prior to completion of phase 2 of the vertical extent drilling, the well was developed on September 21, 2012 to establish proper hydraulic connection with the surrounding aquifer and the groundwater was then sampled and analyzed for CVOCs after a two week stabilization period.

1.1.4 WBldg2 Corridor – MW-140A

As progress was slowed as a result of the large karstic void spaces encountered, a second drill crew was assembled and began drilling at MW-140A in the WBldg2 Corridor from August 20 to 31, 2012, concurrent with the drilling advancement at MW-137A. MW-140A was advanced with a 20-inch air rotary borehole to 49.5 feet bgs and 20-inch steel casing was set and grouted in place at 38 feet bgs after partial collapse of the top of the hole. A 16-inch air rotary borehole was then advanced to set 16-inch steel casing to 62.5 feet bgs followed by a 15-inch air rotary borehole to set and grout 12-inch steel casing to 104 feet bgs. A 6-inch air rotary borehole was then drilled to 195 feet bgs where 6-inch steel casing was set and grouted in place followed by continuing to drill a 6-inch open rock borehole to a TD of 305 feet bgs.

Prior to completion of phase 2 of the vertical extent drilling, the well was developed on September 24, 2012 to establish proper hydraulic connection with the surrounding aquifer and the groundwater was then sampled and analyzed for CVOCs after a two week stabilization period.

1.1.5 Bldg58 Area – MW-138A

MW-138A was drilled in the Bldg58 area from September 25, 2012 to October 26, 2012. MW-138A was advanced using 16-inch CCA air rotary methods to 183 feet bgs where 16-inch steel casing was set. A large clay-filled void was encountered from 145 to 174 feet bgs, so casing was set after reaching 10 foot of competent limestone bedrock (at 183 feet). After the 16-inch casing was set, 12-inch conventional air rotary drilling resumed to 260 feet bgs where 6-inch steel casing was installed and grouted in place.

To complete the advancement of MW-138A, 6-inch conventional air rotary drilling was advanced to a target total depth of 320 feet bgs. No solution features were discovered in MW-138A below 174 feet bgs and the well had penetrated marble, a marker bed near the bottom of the Vintage Formation. The open-rock well was developed on October 26, 2012 to establish proper hydraulic connection with the surrounding aquifer. On November 6, 2012, a dedicated 3-inch Grundfos pump was placed in the well at a depth of 315 feet bgs for sampling and a 2-inch PVC stilling well was installed for water level monitoring. Groundwater samples were collected and analyzed for CVOCs two weeks after development.

1.1.6 SE SPBA – MW-141A

Vertical extent well MW-141A was drilled from November 1 to 21, 2012, in the Southeast corner of the property in the SPBA. Conventional drilling methods were used to advance MW-141A starting with 16-inch air rotary drilling to set 16-inch steel casing at 57 feet bgs. After the 16-inch casing was set, advancement continued with 15-inch air rotary drilling to set 12-inch steel casing at 119 feet bgs, followed by 6-inch air rotary drilling to set 6-inch steel casing at 200 feet bgs. Both casings were grouted in place before the final advancement with 6-inch air rotary drilling to complete MW-141A with an open borehole to 300 feet bgs. No major solution features were discovered in MW-141A below 120 feet bgs. A 2-inch PVC stilling well and a dedicated 3-inch Grundfos pump was placed in the open-rock well for water level monitoring and sampling, respectively. The well was developed on November 21, 2012 to establish proper hydraulic connection with the surrounding aquifer and the groundwater was then sampled and analyzed for CVOCs after a two week stabilization period.

2 Round 2 Vertical Extent Drilling – Multiport Sampler Installation

During the first round of the Vertical Extent Drilling, numerous stacked solution openings were encountered in the upper approximately 200 feet, making the installations difficult, time-consuming and costly. A decision was made to modify the approach for the follow-up phase of the vertical extent investigation, and utilize a multiport sampling system. These modifications are discussed in detail in Addendum #8 to the FSP (GSC, 2013c). Wells MW-136A, MW-137A, MW-139A and MW-140A were deepened using the HQ coring method that produces a 3.77-inch diameter borehole. The core produced using this technique is approximately 2.5 inches in diameter.

Moving forward with coring methods significantly lessened potential risk of ground subsidence. Coring was also advantageous for identifying water bearing zones and produced less investigation-derived waste materials for disposal. The wells were drilled an additional 150 feet beyond the Phase 1 completed depth:

- MW-139A was advanced to a total depth of 470 feet bgs,
- MW-140A was advanced to a total depth of 417 feet bgs,
- MW-137A was advanced to a total depth of 452 feet bgs, and,
- MW-136A was advanced to a total depth of 470 feet bgs.

The rock core was logged by a geological scientist, photographed, and placed into core boxes. Lithology, solution features and their filling materials, fractures, and suspected water bearing zones were noted along with observations of CVOC vapors detected by a PID.

Geophysical logging and heat pulse flow monitoring was completed June 24 to 27 and August 19, 2013 in the boreholes prior to Waterloo Installation, as described in the FSP, Section 4.2.4.13 and detailed in the geophysical report from Advanced Geological Services (AGS), dated October 8, 2013. A combination of observations from the drill cores, drilling conditions, and geophysical logging was used to select discrete sampling/monitoring intervals most likely to represent water bearing zones spaced throughout the open interval of each well bore.

After sampling/monitoring intervals were identified in each of the four vertical extent wells, Waterloo Multilevel Groundwater Monitoring Systems (Waterloos) were installed with sample ports and water level sensors placed at up to five intervals within the open borehole. The discrete monitoring points are separated from each other using water-tight expandable packers positioned at appropriate interval within the borehole. The packers contain an expandable hydrophilic substance with outer materials made of alternating layers of natural rubber, Kevlar and natural rubber that is compatible with the dissolved VOC concentrations in the groundwater at the Site.

A 0.5-foot stainless steel screen containing a dedicated Solinst Double Valve Pump with an inlet and outlet tubing and a Geokon Vibrating Wire Transducer permitted the discreet sampling and water level measurements in each selected sample interval. The screens were connected by schedule 80 PVC and WBZs were sealed off by the packers designed for the HQ-sized borehole. The Waterloo systems were assembled with these pieces, one by one, and built from bottom to top and placed in the well by a trained field team. Each Waterloo System was carefully designed prior to installation based on its desired sampling port intervals using manufacturer-provided design sheets.

Each interval containing a sampling port and a transducer was developed by over-pumping the discrete interval, while monitoring field parameters as described in Section 4.2.4.4 of the FSP

(GSC, 2012b). The dedicated Solinst Double Valve Pumps were used for well development and sampling. After development was completed, each interval was tested for yield and an initial screening groundwater sample was collected and analyzed for volatile organic compounds (VOCs). This information was used to plan sampling procedures as well as determine the initial concentrations of VOCs in each port.

The transducers were calibrated in accordance with procedures provided by the manufacturer. It was determined, however, that the water levels relative to each other were questionable, with transducers in deeper ports appearing to have larger errors. A number of tests were run, and GSC determined that the transducers could be calibrated by comparing the calculated water level from the transducers to a manual measurement of the water level in the sampling tube. The water level in the sampling tube was obtained by inserting a two-wire conductor into the 0.25-inch diameter tubing that was connected to a water tape.

After the initial development and sampling of the Waterloo wells (MW-136A, MW-137A, MW-139A and MW-140A) it became apparent that some sample zones produced very low yields and resulted in a number of concerns that required the development of a specific sampling protocol for these devices. Even with this protocol, there were some ports that had such low yields that groundwater samples and water levels from the transducers could not be obtained.

The Waterloo wells were sampled on multiple occasions, including the 2013 and 2014 Site Wide Comprehensive Sampling Event using the sampling protocol.