KCF Groundwater Inc.

Technical Memorandum

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From: Jim L. Lolcama

To: Steve Snyder
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<u>Subject:</u> Addendum #2 to Field Sampling Plan of Part 2 of the Supplemental Groundwater Investigation, Harley-Davidson Motor Company Operations, Inc. Investigation Methods Summary and Decision Making Criteria for Borehole Testing of Karst Features in Bedrock at the fYNOP Site.

1. <u>Purpose</u>

KCF Groundwater, Inc. (KCF) is pleased to submit this Project Addendum which describes a number of investigation and decision making processes for the upcoming field investigations of intermediate and deep karst beneath the Site. The proposed investigation methods for individual boreholes are water quality profiling and point dilution testing. Cross-hole tracer testing methods are proposed for borehole pairs.

2. <u>Investigation Methods and Decision Making Criteria</u>

<u>2.1 Groundwater Quality Profiling</u>

Technique The groundwater quality profiling method is described in the FSP (Section 4.2.4.6, pp. 39-40; GSC, 2012). Briefly, boreholes and monitoring wells are profiled for groundwater quality to detect and monitor interconnected solution channels or flow conduits in the carbonate bedrock. Rapid migration of stormwater or surface water recharge, and/or acidic groundwater from up-gradient areas of the Site, through the intermediate and deep karst conduit features of the aquifer may result in anomalous values for water quality parameters. These anomalies might include lower electrical conductivity, elevated or depressed temperature, elevated dissolved oxygen concentrations, and/or acidic pH, all of which are associated with the respective sources of the recharge. Examples of investigations of conduit flow in karst aquifers using temperature and hydrochemistry mapping have been described by Alexander et al. (1999); Palmer (2004); and others.

Water quality profiling will be completed both during and after drilling of the boreholes using multi-electrode water quality sensors for direct in-situ measurement of pressure, temperature, pH, conductivity, dissolved oxygen, and turbidity. The location(s) of anomalies will be used to guide the selection of locations in the boreholes for the groundwater velocity testing.

Decision Factors Water quality profiling is a reconnaissance-style investigation method, and can be deployed with relative ease in most borehole settings.

- A borehole should be considered for profiling if bedrock voids in excess of several inches in height are encountered below the water table depth. Voids of this magnitude should be targeted for assessment. The drill site geologist logs the borehole by direct observation and by communicating with the driller who provides specifics. The driller looks for tool ‘drops’ and changes in drill rotation speed and motion. All solution voids and fractures are logged. The occurrences of solution openings in the rock will be examined in their entirety on the log to determine the merit to logging a particular section of the borehole. The PQ coring method, which is planned for the Site, is sensitive to fractured rock and voids.
- To minimize the risk of tool loss in karstic voids due to caving and slumping of void-fill materials, it is recommended that a dummy-probe be lowered down the borehole prior to logging to locate potential problem areas. If problem areas are located, a sleeve should be installed through the caved portions of the borehole. The sleeve could be constructed of 2 inch diameter screen or slotted casing with no sand pack around the screen.
- Karst voids that contain anomalous groundwater quality as a result of this profiling test are candidates for flow velocity measurement using either point dilution or flow metering, although anomalous water quality does not have to be present for velocity

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testing. The flow metering technique has been introduced in Section 4.2.4.13 of the FSP.

- The 1.75 inch diameter, In-Situ Troll 9500 is planned for the water quality profiling and datalogging in 2-inch sleeved, and open boreholes. Other equipment may be used to better suit the bedrock conditions of karst void and void-fill materials, which will be described during the upcoming drilling. The equipment will be calibrated prior to use, and the operation of the sensors will be checked periodically between calibrations using fresh standard solutions provided by the manufacturer. The profiling will be completed by continuous data polling, with frequent data collection, storage, and backup. Data will be graphed and inspected in real time in the field, and close inspection of anomalous water quality zones will be completed as the zones are encountered. Data graphs of all water quality parameters with depth will be created and annotated soon after the data has been collected.

2.2 Point-Dilution Testing of Flow Velocity

Technique The point-dilution tracer testing method is described in the FSP (Section 4.2.4.8, pp. 43-45; GSC, 2012). Briefly, the testing method is applied to a flow conduit feature which has been identified by examination of: 1. the Site 3-D karst model; 2. geologic log of the borehole; and 3. groundwater quality profile of the saturated, open or screened section(s) of the borehole. The conduit feature would be isolated from the borehole using either inflatable packers, a compressible rubber K-type packer set-up, or PVC piezometer materials. For the PQ-cored sections of the vertical extent/DNAPL investigation boreholes, which may be too narrow for packer insertion, or where the borehole wall is too uneven for proper packer inflation, two different options are presented to gain access to the test interval. One option is to insert a PVC piezometer with a 100-slot screen and geotextile filter wrap through the test zone. A shale-trap would be connected to the piezometer just above the screen, and a grout seal would be constructed above the shale-trap to block the vertical flow of water through the borehole. A second option is to remove the core barrel from the outer spin casing and insert a K-packer which is attached to a narrow diameter threaded metal piping through

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the outer casing to the desired depth. While holding the K-packer in place, the outer spin casing is withdrawn a pre-determined distance to expose the test interval. The K-packer blocks the flow of water vertically down the borehole.

The down-hole sensor assembly and injection hose is lowered into place inside of a perforated metal sleeve which extends below the K-packer, or in the open borehole. The 0.75 inch diameter In-Situ AquaTroll is planned for the velocity testing. The relatively small diameter of the AquaTroll maximizes borehole clearance which reduces the risk of tooling loss down the hole. We reserve the right to change the testing equipment to better suit the bedrock conditions of karst void and void-fill materials, which will be described during the upcoming drilling. The equipment calibration will be checked periodically using fresh standard solutions provided by the manufacturer. The sensors will collect and store groundwater temperature and conductivity data throughout the test.

A small volume of tracer, measured by a totalizing flow meter, will be pumped into the test interval to surround the sensor assembly. The hydrogeologist will halt the pumping of the tracer when a slug has been achieved inside of the test interval, which will be determined using the real-time readings from the downhole sensors. De-ionized water tracer is planned for the velocity testing due to simple handling and pumping procedures, tracer availability, and lack of interference from turbidity which can occur with dye tracers. The sensors will measure and record the initial concentration, and the dissipation of the tracer slug, in one minute intervals. A polling feature of the AquaTroll will allow the hydrogeologist to inspect the conductivity in the test zone at intervals as short as several seconds. The test will be halted when the majority of the tracer has dissipated, or when a sufficient number of concentration data points have been collected, which in most cases should take less than one hour.

The velocity of the groundwater will be determined from the volume of tracer, the rate of dissipation of the tracer into the aquifer, and the dimensions of the borehole and test interval. Test interpretation methods are described by Freeze and Cherry (1979; pp. 426-430).

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Decision Factors A potential flow conduit can be a solution feature in the carbonate bedrock at the Site which can range from several inches to tens of feet in height and more, and which is not tightly packed with terra-rossa clay. The location and type of the void-fill material can be deduced from the resistance and rotational pressure of the drill as it passes through the void. For example, terra-rossa clay will create substantial penetration and rotation resistance, which is indicated by the drill controls and is communicated by the driller to the drill site geologist. Where strong evidence exists for a void being filled completely with clay, flow velocity testing will not be completed. Where open, water-filled areas of a solution feature are identified, the water quality profile for a borehole should be overlain on the geologic log and inspected to identify any water quality anomalies that may exist. The open and partially-open water-filled karst features would typically contain whatever water quality anomalies are discovered, and those anomalies would be prioritized for flow velocity testing.

2.3 Cross-Hole Groundwater Tracer Testing

The cross-hole groundwater tracer testing method is described in the FSP (Section 4.2.4.9, pp. 45-47; GSC, 2012). Briefly, groundwater tracer testing is planned to be performed on the Site to investigate intermediate and deep karstic flow pathways in the following areas: 1) at the locations of the deep stratigraphic borings and 2) beneath Codorus Creek and continuing westward to the west-levy monitoring wells. Although not currently part of the proposed scope, this testing procedure may be considered for use, 3) southeast of, and due south of the Site; and 4) in suspected contaminant source areas.

The tracer testing described below would be conducted between two or more boreholes using direct and real-time detection and quantitative interpretation methods. The tracer would be either salt brine solution or Rhodamine WT (RWT) dye. The decision factors on choosing the tracer are discussed below. Pairs or groups of wells may be selected for quantitative tracer testing at one or all of the four general areas described above.

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Decision Factors To be selected for testing, wells would need to exhibit strong evidence suggesting conduit flow including some or all of the following factors: substantial-sized, open or partially-open water-filled void(s); anomalous groundwater quality indicating conduit flow of surface or up-gradient recharge; and conduit-flow velocity from point dilution testing. The range of 0.1 to 1.0 ft/min would be an approximation of conduit flow velocity, however the velocity associated with conduit flow is dependent on the geometry of the conduit. The appearances of a flow conduit system would have to exist for testing to take place. For example, a single small water-filled void, inches in size, would not be considered. However, a cluster of several inch sized voids containing mostly water would be considered. Larger voids than this may be considered for testing using cross-hole methods. Other evidences may also be found including: compressed air or water interconnections with adjacent boreholes during air-rotary drilling; substantial local anisotropic (directional) drawdown in the water table; and suggested pathways from the 3-D karst site models.

Monitoring wells or boreholes that are planned for tracer injection should be evaluated for their recharge capacity prior to their selection. Since loss of circulation during air-rotary drilling or PQ-core drilling may have occurred, the groundwater yield from the borehole interval may not be available. The recharge capacity of the well or borehole can be determined using freshwater injection testing. A fresh-water injection test resembles a specific capacity test of a well, but with water injection rather than withdrawal. A successful test would show substantial injection capacity with minimal water table rise, and would indicate that the well or borehole is a good candidate for tracer injection. Discrete vertical zones to be monitored within a well bore will be determined from borehole logs and observations, water quality profiling, and point dilution testing results. Each borehole may contain up to four sets of sensors at selected depths in the saturated portion of the borehole, or in the screened portion of the piezometer.

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At this early point, when the boreholes have not yet been drilled and information on velocity, turbidity, interconnectivity, and injection capacity are not available, the decision on tracer type and concentration is necessarily general. The decision on which tracer and the tracer volume and concentration will consider possible interferences such as background turbidity and salinity, the planned quantity and rate of injection, the possible receptors along the flow path, and the potential for dye being noticed. Elevated turbidity in conduit flow is a common occurrence due to scouring and transport of sediment fill material by groundwater, and the turbidity will interfere with the detection of the RWT dye tracer. An RWT dye tracer could potentially color the artesian groundwater discharges in the Codorus Creek bright red, depending on the mixed concentration reaching the creek from the injection locations, and therefore dye should be used sparingly. Salt brine solution is colorless, and it is harmless to aquatic life during short-term exposures at the expected concentrations.

Injection of the tracer should be accomplished in a short time interval and at substantial rates to create a concentrated (un-mixed) slug of tracer within the aquifer. Wells or boreholes with small injection rate capacity should not be used. The volume of tracer to be injected per well will be determined using the groundwater velocity information and the injection rate capacity of the well. For RWT tracer, the tracer solution concentration should be sufficiently dilute to prevent the artesian spring discharges from coloring Codorus creek; between 20 and 30 parts per billion (ppb) is recommended for the stock solution, with the concentration of the solution never exceeding 100 ppb. Around 30 ppb concentrations of RWT can usually be detected visually in clear water.

If dye-tracing is to be completed, a substantial quantity of dye tracer would need to be mixed and stored on-site in a tank in advance of testing. The electronic sensors, whether for dye detection or brine detection, will be properly tested to verify their operation prior to deployment. Brine tracer can be supplied in bulk volumes (estimated 4,000 gallons per truckload) by a local provider. The ready availability of brine solution can be a benefit at the time of testing. A tank of fresh water would be available for injection into the well or borehole to flush the tracer into the aquifer.

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Environmental considerations for the use of tracers are listed and addressed herein:

- There are no known water supply wells, either public or private that are within the expected pathway of the tracers where tests are currently planned. The likelihood of impact to local wells is small, and the duration of impact would be short, in the unlikely event that it occurs at all.
- RWT dye tracer is commercially available non-toxic dye. Exposure to salt solution is not a health risk, and the salt brine that will be used is comprised of sodium-chloride only.

Monitoring for the tracer arrival would continue until breakthrough is obtained, or until sufficient time has passed to state with confidence that arrival is unlikely for that location. As a guideline, (2 X (distance/velocity)) would be useful for estimating the monitoring period for tracer breakthrough.

Assumptions and Limitations

The opinions expressed in this memo are based upon our current level of understanding of the conditions of the subsurface at the Site. The methods presented in this memo may be modified in light of future investigation results on Site conditions. The description of the karstic bedrock system contained herein is intended to provide insight towards designing an exploration and testing program for karst bedrock. Much information has yet to be discovered about the overburden and bedrock. It should not be assumed by the reader that the conditions that have been discovered at the Site are representative of the conditions of the bedrock in the areas yet to be explored.

References

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Sincerely yours,

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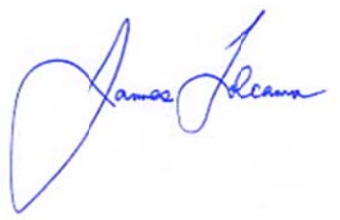

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