SUPPLEMENTAL REMEDIAL INVESTIGATION (RI) REPORT ADDENDUM

Former Hulett Lagoon Site
Camdenton, Missouri

Submitted To: Missouri Department of Natural Resources
Hazardous Waste Program
Superfund Section
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1.0 INTRODUCTION AND BACKGROUND

Golder Associates Inc. (Golder) was retained by the City of Camdenton to perform supplemental Remedial Investigation/Feasibility Study (RI/FS) activities for the Former Hulett Lagoon Site (Site) located in Camdenton, Missouri (Figure 1). The RI/FS activities were conducted in general accordance with the scope of work identified in the Administrative Settlement and Abatement Order on Consent for Supplemental RI/FS (AOC) for the Site dated March 21, 2016 (MDNR 2016). The field program was conducted in accordance with the Supplemental RI/FS Work Plan (“the work plan”), which was submitted to the Missouri Department of Natural Resources (MDNR) and the City of Camdenton in May 2016 (Golder 2016a). This report provides the findings of the Supplemental RI investigation.

1.1 Site Background

The Site is located in the western portion of the City of Camdenton, Camden County, Missouri. The Site includes both the Hulett Lagoon Facility and the Sunset Drive Facility (MDNR, 2016). The Mulberry Well is a municipal well owned by the City of Camdenton. The Mulberry Well was drilled in 1986 to a depth of approximately 900 feet below ground surface (feet bgs), is cased with 12-inch steel casing to approximately 400 feet bgs, and open borehole completion below to total depth. The well is located approximately 400 feet east-southeast of the Sunset Drive Facility and 1,000 feet south of the former Hulett Lagoon Facility (Figure 2).

In February 1997, trichloroethene (TCE) was detected in the Mulberry Well. In 1998, the City reported the TCE concentration in the pump effluent exceeded the Maximum Contaminant Level (MCL) for drinking water and removed the Mulberry Well from service to the public. The City has since routinely pumped the Mulberry Well with the existing vertical turbine pump to maintain hydraulic control of the TCE plume in the production zone, to prevent migration to other City wells.

Several investigations were conducted at the Site by MDNR and Secor International Incorporated (on behalf of the Hamilton Sundstrand Corporation) between 1997 and 2007. These include risk assessments, the development of a groundwater flow model, and remedial investigations. A more detailed summary of the previous investigations is provided in Section V of the AOC.

For consistency with the 2003 Remedial Investigation Summary Report (SECOR, 2003) and subsequent investigations, the Perched Zone refers to the unit above the argillaceous zone and the Deep Aquifer refers to the unit below the argillaceous zone. Although the entire thickness of the Deep Aquifer unit is generally referred to as an aquifer, the majority of flow is likely constrained to discrete water producing zones that
comprise a small percent of the upper portion of the total rock mass. These discrete water producing zones will collectively be referred to as the Mulberry Well Production Zone.

1.2 Investigation Objectives

The objectives of the RI/FS were to (1) investigate the discrete water-producing zones of the aquifer that are contributing to the groundwater contamination near the Mulberry Well and (2) use the investigation results to develop remedial alternatives for optimizing the City of Camdenton’s Mulberry Well to prevent the migration of TCE. This report documents the field activities and results of Part (1) of the aforementioned scope of work, which included down-hole geophysical testing, groundwater sampling and well pumping tests. The field program methods are described in Section 2. A discussion of investigation results is included in Section 3. Proposed future actions for the Site are discussed in Section 4.
2.0 REMEDIAL INVESTIGATION

The field activities are separated into two tasks: the pre-design assessment and the pumping test. The RI/FS Pre-Design Assessment was conducted in August and September of 2016. The pumping test was conducted in October and November of 2016. The protocols for and results of each task and subtask are described in the sections below.

2.1 Task 3A – Pre-Design Assessment

2.1.1 Visual Assessment of Existing Pump

To access the Mulberry Well, the existing vertical turbine pump and associated down-hole equipment was removed from the well. The pump motor was staged inside the pump house. The pump riser and bowls were staged outside the pump house on wooden cribs underlain by plastic sheeting. Layne Christensen (the drilling contractor) indicated the need for some maintenance on the line shaft and centralizers if the pump was ever returned to service. No other deficiencies were noted during the inspection.

2.1.2 Down-Hole Geophysical Testing

Geophysical testing was conducted to assess the condition of the casing and to document the geologic characteristics of the borehole, including the presence of fracture zones, bedding planes, and solution features. In addition, flow logging was performed to evaluate which fractures are likely contributing majority of the flow to the open hole interval. The geophysical logging included caliper logging, full waveform sonic logging, teviewer logging, temperature-conductivity logging, and flow logging. Geophysical logs are included in Appendix A.

2.1.2.1 Caliper Logging

Caliper logging was conducted to determine the physical dimensions of the well, including the diameter of the casing and borehole. The rate of data acquisition was approximately 15 feet per minute. The casing diameter was generally uniform in diameter at 12 inches to a depth of approximately 398.5 feet below the top of casing (btoc). From 398.5 to 423.5 feet btoc, the borehole diameter enlarged to approximately 14 inches. Below 423.5 feet btoc, the borehole diameter narrowed to approximately 12.2 inches, with discrete zones of increased diameter likely associated with bedding material washout. Squeezing or collapsed zones where the borehole diameter decreased to at least one inch less than the average 12.2 inches are as follows.

- 448.7 feet btoc – approximately 1 inch thick zone that narrows to approximately 10.5-inch diameter
- 450.3 feet btoc – approximately 1 inch thick zone that narrows to approximately 11-inch diameter
679.4 feet btoc – approximately 1 foot thick zone that narrows to approximately 6-inch diameter

The caliper tool had difficulty passing the feature at 679.5 feet btoc upon retrieval. Therefore, centralized geophysical equipment (i.e., televiewer and spinner) were not advanced past this feature. The total depth of the well was estimated at approximately 895 feet btoc based on depth of travel of the fluid temperature – conductivity tool.

2.1.2.2 Full Waveform Sonic Logging

Full waveform sonic logging was conducted in the saturated portion of the well casing to provide an indication of cement grout installation integrity using a cement bond log (CBL). The tool was zeroed at the top of the steel casing and the frequency used was 15 kilohertz (kHz). The rate of data acquisition was approximately 7.5 feet per minute. The results of the log indicated a generally good bond between the casing-cement and cement-formation interfaces.

2.1.2.3 Televiewer Logging

Televiewer logging was conducted along the open borehole portion of the Mulberry Well to a depth of approximately 672 feet btoc. Golder used an acoustic (ABI) televiewer to provide a continuous oriented 360° unwrapped image of the borehole wall. These images were oriented using data recorded by a three-axis magnetometer and three accelerometers incorporated in the tool. The ABI tool was used below the water table depth. The rate of data acquisition was approximately 2.5 feet per minute. Televiewer logs indicated the presence of bedding features oriented approximately horizontal.

2.1.2.4 Temperature – Conductivity Logging

Temperature and conductivity logging was conducted along the open borehole portion of the Mulberry Well to a depth of approximately 895 feet btoc. Measurements were collected under static conditions by gradually lowering and raising the tool in the well. Changes in temperature and conductivity measured along the borehole are indicative of groundwater flow zones. Zones of potential flow were evaluated further during flow logging. The rate of data acquisition was approximately 10 feet per minute.

2.1.2.5 Flow Logging

Flow logging was conducted along the length of the open borehole to develop a vertical profile of the relative groundwater production capacity in the Mulberry Well. Measurements were collected under static and dynamic conditions by gradually lowering the spinner flowmeter in the saturated portion of the well. For the static (ambient) case, the flowmeter was run at 20, 30 and 40 feet per minute. For the dynamic case, the associated submersible pump was set at an extraction rate of approximately 100 gallons per minute and the tool was run at 30 and 40 feet per minute runs along the open borehole.
These measurements, in conjunction with the temperature – conductivity logging, were used to determine the primary subsurface intervals which contribute groundwater to the overall production of the well. Discrete groundwater flow zones at well depths of 450, 525, 557 and 575 feet btoc were identified, and appeared to be horizontal bedding features. Additionally, some flow was detected immediately below the well casing from 400 to 425 feet btoc. Negligible flow was detected from below 600 feet btoc in the Mulberry Well. The spinner flowmeter log is presented in Appendix A.

### 2.1.3 Pre-Design Interval Testing

#### 2.1.3.1 Groundwater Sampling

Inflatable packers were used to isolate the discrete groundwater flow zones identified by geophysical logging. The Intervals included the following.

- 395.2 – 429.7 feet btoc
- 437.4 – 471.9 feet btoc
- 511.7 – 546.2 feet btoc
- 532.8 – 567.3 feet btoc
- 563.9 – 598.4 feet btoc

#### 2.1.3.2 Sampling Protocol

Sampling and analyses followed the Golder Technical Guideline for Collection of Groundwater Quality Samples, as well as MDNR direction, approval, and guidance regarding sampling, Quality Assurance/Quality Control (QA/QC), data validation, and chain of custody procedures.

Each interval was purged for approximately 39 to 56 minutes, with pump discharge monitored for stabilization of pH, temperature, conductivity and turbidity prior to sampling. At least five system volumes (sample interval plus drill casing) were purged prior to sampling.

A total of five (5) groundwater samples (one from each interval) were collected directly into laboratory-supplied and labeled containers and packed in a cooler with ice to maintain a temperature of approximately four degrees Celsius. Samples were shipped to ALS Environmental in Houston, Texas and analyzed for Volatile Organic Compounds (VOCs) using United States Environmental Protection Agency (EPA) method 8260B.

Validated groundwater analytical results for the Mulberry Well pre-design test intervals are discussed further in Section 3. Groundwater sample collection and chain-of-custody forms and analytical reports are included in Appendix B. A summary of observed drawdown in the Mulberry Well during Pre-Design groundwater sampling activities is included in Table 1 below and drawdown plots are included in Appendix C.
Table 1 – Observed Drawdown – Pre-Design Groundwater Sampling

<table>
<thead>
<tr>
<th>Interval (feet btoc)</th>
<th>Pumping Duration (minutes)</th>
<th>Flow Rate (gpm)</th>
<th>Drawdown (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>395.2 – 429.7</td>
<td>47</td>
<td>77</td>
<td>105*</td>
</tr>
<tr>
<td>437.4 – 471.9</td>
<td>48</td>
<td>78</td>
<td>145</td>
</tr>
<tr>
<td>511.7 – 546.2</td>
<td>39</td>
<td>95</td>
<td>12</td>
</tr>
<tr>
<td>532.8 – 567.3</td>
<td>40</td>
<td>93</td>
<td>11</td>
</tr>
<tr>
<td>563.9 – 598.4</td>
<td>56</td>
<td>93</td>
<td>13</td>
</tr>
</tbody>
</table>

Notes:  * - the maximum drawdown in this interval was limited due to the water level drawdown nearing pump elevation

gpm – gallons per minute

The intervals from 400 feet to 520 feet btoc accounted for approximately 25 percent of the flow observed during flow logging and exhibited over 100 feet of drawdown at an approximate pumping rate of 78 gpm. The intervals from 520 feet to 600 feet btoc accounted for approximately 75 percent of the flow observed during flow logging and exhibited an average drawdown of 12 feet at a pumping rate of 94 gpm. Observed drawdown in the discrete groundwater flow zones is in general agreement with the results of flow logging.

2.2 Task 3B - Pumping Test
A constant rate pumping test and subsequent recovery test were conducted in the Mulberry Well to determine the rate at which groundwater would need to be removed from the well to maintain hydraulic containment of groundwater contaminants in the Mulberry Well Production Zone.

2.2.1 Pumping System Setup
Based on the results of groundwater sampling within the Mulberry Well during the pre-design phase and in coordination with the MDNR, an inflatable packer was used to isolate the Mulberry Well Production Zone, located between 400 and 600 feet btoc. The packer (inflated below the pumping zone) was set at 598.4 feet btoc.

A temporary pumping system consisting of a 4-inch Grundfos submersible pump was installed in the Mulberry Well to conduct the constant rate pumping test. The submersible pump was hardwired into the existing vertical turbine pump starter inside the pump house. The submersible pump was set at a depth of approximately 160 feet below the static water level or approximately 240 feet above the top of the test zone. At the surface, the submersible pump riser pipe was plumbed into the vertical turbine pump discharge pipe and allowed to run through the existing flow meter and aeration system. Additionally, the pump riser pipe was fitted with a side discharge to allow flow cell hook-up for groundwater sampling and for measurement of field parameters.
2.2.2 Monitoring Well Network
Prior to starting the pumping test, depth to groundwater was measured in the select monitoring wells (MW-2, MW-9, MW-13, MW-14, MW-16, MW-17, and MW-23). The potentiometric surface for the select monitoring wells is shown on Figure 3. Deep Aquifer wells, MW-2, MW-14, MW-16, MW-17, and MW-23 and Perched Zone wells MW-9 and MW-13, were instrumented for monitoring during the pumping test. Pressure response measurements were used to determine the Mulberry Well’s radius of influence.

2.2.3 Constant Rate Test
The constant rate pumping portion of the test was initiated on October 24, 2016 at a nominal discharge rate of 105 gallons per minute (gpm) for 92 hours. Water levels were monitored in the Mulberry Well and in select observations wells (Deep Aquifer: MW-2, MW-14, MW-16, MW-17, and MW-23; Perched Zone MW-9, MW-13,) using electronic pressure transducers and manual readings. Water level and flow rate in the Mulberry Well was generally measured at the following frequencies:

<table>
<thead>
<tr>
<th>Elapsed Time</th>
<th>Monitoring Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15 minutes</td>
<td>5 seconds</td>
</tr>
<tr>
<td>15 - 60 minutes</td>
<td>1 minute</td>
</tr>
<tr>
<td>1 - 2 hours</td>
<td>5 minutes</td>
</tr>
<tr>
<td>2 - 4 hours</td>
<td>15 minutes</td>
</tr>
<tr>
<td>4 - 92 hours</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

Transducer data was collected in the monitoring wells at approximately one minute, 15 minute and one hour increments. Water levels were measured manually in the monitoring wells at approximately 6 to 12 hour intervals depending on access constraints. A barometer located at the Mulberry Well pump house was used to measure changes in atmospheric pressure during the pumping tests for data correction.

The constant rate test was stopped on October 28, 2016, followed by 168 hours of monitored recovery.

2.2.4 Recovery Test
The purpose of the recovery test was to estimate aquifer transmissivity in the Mulberry Well Production Zone (e.g. 400 to 600 feet bgs). The recovery period was monitored from October 28 through November 4, 2016. Groundwater levels in the Mulberry Well and select monitoring wells (Deep Aquifer: MW-2, MW-14, MW-16, MW-17, and MW-23; Perched Zone MW-9, MW-13) were monitored for recovery and, in the case of the monitoring wells, for residual drawdowns. Groundwater levels were measured at similar frequencies as those described above for the constant rate test.
Upon completion of the recovery period, the City of Camdenton restarted the pump on November 8, 2016 to maintain hydraulic control within the well influence zone.

The water level measurements collected during the recovery tests were analyzed with various software packages which are discussed further in the following sections. Plots of the pressure responses and pumping rates measured during the constant rate and recovery tests are included in Appendix C.

2.3 Groundwater Sampling

Three (3) groundwater samples were collected during the pumping test and analyzed for VOCs, hardness, metals, mercury, alkalinity, and total organic carbon (TOC) using EPA methods 8260B, M2340B, SW6020, SW7470, SM2320B, and SW9060, respectively. Sampling was conducted by first purging the stainless steel sample port for approximately 15 seconds, followed by filling laboratory supplied sampling containers. The samples were packed in a cooler on ice and shipped via overnight courier to ALS Environmental Laboratory in Houston, Texas and analyzed for VOCs, Resource Conservation and Recovery Act (RCRA) metals, calcium, magnesium, hardness, alkalinity, and total organic carbon. Groundwater sample collection and chain-of-custody forms and analytical reports are included in Appendix B.

2.4 Investigation-Derived Waste

Groundwater generated during the constant rate test was periodically sampled and analyzed for VOCs, and other compounds as described above. Field parameters (i.e., pH, temperature, conductivity, and turbidity) for discharge samples were measured via a flow cell plumbed to the discharge pipe. After sample collection, the remaining groundwater was discharged according to the procedures described in the Investigation-Derived Waste Plan (Golder 2016b).
3.0 RESULTS

3.1 Groundwater Sample Results

Groundwater analytical detections for the pre-design interval testing and pumping test are summarized in Tables 2 and 3. Groundwater analytical results were compared to EPA maximum contaminant levels (MCLs). The following compounds were detected above applicable screening levels:

- TCE exceeded the US EPA MCL value (5.0 µg/L) in all of the samples collected during the pumping test (MWPT-1, MWPT-3, and MWPT-4) as well as the samples collected during the pre-design interval testing (Mulberry Well (395-429, 437-472, 511-546, 532-567, and 564-598) with values of 58, 59, 60, 240, 140, 30, 58, and 52 µg/L, respectively.

Groundwater samples from the two uppermost discrete flow zones (395-429 and 437-472 feet btoc) yielded TCE concentrations three to five times greater than the average concentration in the lower three discrete zones (511-546, 532-567 and 564-598 feet btoc).

The results of the groundwater sampling during the pre-design interval testing were used to help determine the interval that was selected for the pumping test. Based on the results described above as well as the results for other geophysical logging described in Section 2.0, an approximate depth interval of 400 and 600 feet btoc was selected for testing.

It should be noted that none of the groundwater samples collected during the 92-hour constant rate pumping test yielded detections above the NPDES monthly discharge limit and were indicative of flow primarily originating from the lower three discrete flow zones (511-546, 532-567 and 564-598 feet btoc) based on similar TCE concentrations and observed drawdown.

The results for metals and general chemistry presented in Table 3 will be discussed in more detail in the Feasibility Study Addendum as they relate to potential groundwater treatment options.

3.1.1 Quality Assurance/Quality Control

To verify the accuracy and reproducibility of the laboratory analytical results, the analytical laboratory implemented a quality assurance/quality control (QA/QC) program which included laboratory replicate samples, method blanks, and control standards. Golder also collected one field duplicate sample and blank samples (trip blank, field blank and rinse blank). Level 2 data validation was conducted on the QA/QC data, and the validation yielded the following results:

- Chloroform and chloromethane were detected in the field blank (FB-1) and chloroform was detected in the rinse blank (RB-1). These compounds were not detected in any of the samples or other method blanks or the trip blanks.

- The duplicate sample (DUP-1) had low relative percent differences (RPD) when compared to its associated sample (MWPT-1) and therefore no data qualifiers were needed.
No results required rejection or qualification based on MS/MSD recovery exceedances or RPD criteria exceedances.

Five groundwater detection results were laboratory flagged “J” because the analyte was detected between the Method Detection Limit (MDL) and the Reporting Limit (RL). No additional items required the qualification of data results by Golder.

The QA/QC data and validation results are included with the laboratory analytical reports in Appendix B.

3.2 Pumping Test Analysis and Results

3.2.1 Analytical Analysis Methods
The pumping test data was analyzed with SAPHIR, distributed by Kappa Engineering Inc. SAPHIR is an analytical well test analysis software package that includes multiple near well, formation and boundary flow models. It also includes the semi-log pressure derivative data to improve the diagnosis of the flow model on the log-log plot. Because the storativity and skin (i.e., near well permeability) are highly correlated, the approach is to input the storativity and match for the skin value. The storativity was assumed to be $1 \times 10^{-4}$, consistent with a confined aquifer. Parameters derived from the analysis were used for the numerical model discussed below.

3.2.2 Numerical Modeling Approach
Because the Deep Aquifer observation wells are approximately 200 to 300 feet above the Mulberry Well Production Zone, a layer-cake model comprised of horizontal layers was constructed to analyze the Deep Aquifer observation well data using the numerical model package in SAPHIR. The objectives of the model were to assist with the overall understanding of the test response that can better represent the geometry of the pumping and observation wells versus analytical methods. A five layer model was developed (see Figure 5D of Appendix D). For purposes of running the model, the hydrogeological properties of the Mulberry Well Production Zone layer were set based on the analytical analysis of the pumping well test data. Those properties are referenced in Table 5 of Appendix D. The vertical boundaries of the model were set far enough from the pumping well such that they would have no influence on the test data. Top and bottom boundaries were set to no-flow. The storativity and hydraulic parameters of the layers above and below the Mulberry Well production zone were adjusted to match the observation well responses.

3.2.3 Measured Aquifer Response
The distribution of observation well responses show significant upward attenuation of pressure propagations with drawdowns on the order of 1 foot in the Deep Aquifer observation wells compared to 20 feet in the Mulberry Well. As discussed previously, the Deep Aquifer observation wells are completed approximately 200 to 300 feet above the mid-point of the Mulberry Well Production Zone (500 feet btof), at radial distances between 600 and 1,400 feet from the Mulberry Well, yet show no distinct lateral variation in drawdown over these distances. This suggests that the cone of depression in the underlying aquifer is
relatively “flat” and broad versus steep and aerially constrained, consistent with high transmissivity and low storativity for the Mulberry Well Production Zone.

Drawdown was not observed in the two Perched Zone observation wells, MW-9 and MW-13. The drawdown measured at the end of pumping in the Mulberry Well and observation wells are presented in Appendix D.

### 3.2.4 Mulberry Well Pumping Test Analysis Results

A narrative of the flow model from the shapes and slopes of the semi-log pressure derivative data is summarized below and included in Appendix D.

**Pumping Test Synopsis**

- **Up to 0.1 hours**: There is no hump in the derivative data and little separation between pressure and pressure derivative data that indicates negative skin, or local well permeability that is higher than the aquifer permeability (likely due to drilling damage or washout). A negative skin is often attributed to water conductive fractures connected to the wellbore that is consistent with flow logging results that shows discrete zones in the interval 400 to 600 feet btoc in the Mulberry Well contributing majority of the flow to the well.

- **0.1 to 50 hours**: The flat derivative data is indicative of radial flow to the well (i.e., flow geometry of 2). This suggests that flow is being controlled by bedding plane fractures that, because they are flat and are oriented perpendicular to the well, resulting in the radial flow geometry. If flow was occurring in vertical to sub-vertical tectonic structures, the resulting flow geometry would likely be between one-dimensional flow (i.e., flow geometry of 1) and radial flow.

- **50 to 92 hours**: End effect that is common in well test data, i.e., noise in the data that approaches the small pressure change at the end of recovery that masks the flow model.

Good matches between the flow model and the pumping test results verify the selection of the flow model and hydraulic parameters that are summarized below:

- **Skin**: -4.2
- **Transmissivity**: $1 \times 10^{-3}$ m$^2$/s
- **Hydraulic conductivity**: $2 \times 10^{-3}$ cm/s (assumes even distribution of flow in the interval 400 to 600 feet btoc)
- **Boundaries**: none detected within the radius of influence
- **Radius of influence (lower bound)**: 2 miles

### 3.2.5 Numerical Model Analysis Results

The lack of partial penetration and double porosity effects in the pumping well response indicates a downward vertical flux due to relatively low hydraulic conductivity in zones above and below the Mulberry Well Production Zone, compared to the horizontal flow encountered within the Mulberry Well Production
Zone. Conversely, the higher diffusivity from lag time measured in observations wells suggests good connectivity that is likely controlled by a low storativity connection that allows pressures to propagate in lower hydraulic conductivity strata.

The layer-cake numerical model was used to evaluate order-of-magnitude properties between the pumping well and observation wells. The simulated drawdown of 1 foot shows good consistency with measured drawdown of 1 foot. Overall, the model simulation indicated a low storativity (10^{-6} to 10^{-5})/low hydraulic conductivity (10^{-9} to 10^{-8} cm/s) connection between the monitoring wells and the Mulberry Well Production Zone. This is consistent with the recovery measured in the Deep Aquifer observation wells.

3.2.6 Results Summary and Conceptual Model

For the duration of the test, the computed or theoretical radius of influence of the Mulberry Well is between 2 and 9 miles, within the range attributed to storativity sensitivity in the calculation. Moreover, the radius of influence will increase with the extended pumping duration. For models that assume flow is evenly distributed over relatively large thicknesses of strata (e.g. the previous site conceptual model – see Figure 4), versus discrete zones as is the case for the Mulberry Well Production Zone associated with the Mulberry Well (e.g. the revised site conceptual model – see Figure 5), the cone of depression from pumping will be underestimated. In reality, the majority of the flow is in the Mulberry Well Production Zone between 400 to 600 feet bgs and, within this interval, is likely constrained to bedding planes that are zones with significantly higher and lower hydraulic conductivity compared to the bulk hydraulic conductivity.

The five Deep Aquifer monitoring wells each responded to the pumping test in a similar fashion. That indicates a degree of hydraulic connection and that the pumping rate was sufficient to induce downward flow toward the production zone connected to the Mulberry Well; with extended pumping duration, the magnitude of downward flow will increase. The groundwater flow conditions described above are illustrated in the revised site Conceptual Model (see Figure 5).

No responses to pumping were observed in the two monitoring wells completed across the Perched Zone, suggesting relatively poor vertical hydraulic connection to this zone. Additionally, outside pumping influences (e.g., non-Mulberry Well pumping) were not observed in the pumping test and recovery period data.

Using aquifer parameters estimated from the pumping test analysis and the Theis method (time-variant, confined aquifer), expected drawdown from pumping was simulated in the Mulberry Well Production Zone, which corresponds to the approximate radius of influence of the Mulberry Well. At a pumping rate of 105 gpm and time of 300 days, the estimated radius of influence extends at least to the Lake of the Ozarks on the north, east and west. It is inferred that the lake acts as a groundwater divide, where the influence of pumping ends. The simulated radius of influence of pumping in the Mulberry Well is shown on Figure 6.
3.3 Evaluation of Hydraulic Containment

The extent of hydraulic containment of the Mulberry Well was evaluated using the results of the pumping test analysis. As discussed in the pumping test analysis results, the upper portion of the Deep Aquifer where the monitoring wells are screened, approximately 175 to 240 feet bgs, exhibits hydraulic conductivity several orders of magnitude less than the Mulberry Well Production Zone ($10^{-3}$ cm/s versus $10^{-8}$ cm/s). Groundwater flow in a layered medium, where hydraulic conductivity contrast between zones is two to three orders of magnitude, can be expected to behave as Freeze & Witherspoon describe (see Plate 1 below). Under these conditions, groundwater flow in the shallow zone (lower $k$ – $10^{-8}$ cm/s) consists primarily of downward vertical flux towards the deep (higher $k$ – $10^{-3}$ cm/s) Mulberry Well Production Zone, where flow is predominantly horizontal and with subdued gradient. This flow condition is consistent with pumping test observations (i.e. radial flow along bedding planes and uniform drawdown), the numerical analysis of pumping test data, and the conceptual model (Figure 5).

Plate 1 – Expected Groundwater Flow in a Layered Medium with Hummocky Topography (Adapted from Freeze & Witherspoon, 1967)

Pumping from the Mulberry Well induces horizontal flow from the Mulberry Well Production Zone in high permeability bedding plane fractures between 400 and 600 feet. This zone is expected to be aerially extensive as no boundaries were detected in the pumping test response for a computed radius of influence of 2 to 9 miles.

The drawdown from pumping in the Mulberry Well Production Zone induces diffuse downward flow of impacted water and diffuse upward flow of non-impacted water because the vertical hydraulic conductivity of the bulk rock immediate above and immediately below are several orders of magnitude lower compared to the horizontal hydraulic conductivity within the conductive bedding planes. Once the impacted water is within the conductive bedding plane, travel time is relatively short to the well because of the high horizontal hydraulic conductivity. Because of the high diffusivity (transmissivity/storativity) of the Mulberry Well Production Zone bedding plane fractures connected to the Mulberry Well, the radius of influence propagates relatively rapidly and results in broad cone of depression (see Figure 6).
Hence, given the broad downward gradient that can be induced by pumping from the Mulberry Well at moderate rates in response to a broad cone of depression and the upward flow from the strata below conductive zone, the conceptual model is consistent with achieving containment as the water conductive zones connected to the Mulberry Well are acting as drain which collects groundwater from surrounding low diffusivity zones.
4.0 CONCLUSIONS AND FUTURE ACTIONS

The results of the Supplemental Remedial Investigation indicate that a continuous pumping rate of approximately 105 gpm is capable of inducing downward vertical flow to the Mulberry Well Production Zone over the extent of the Deep Aquifer plume.

During the pumping test investigation, the Mulberry Well Production Zone was the shallowest groundwater production zone encountered in the vicinity of the TCE plume. This was demonstrated by widespread, uniform drawdown response to the constant rate pumping test. Pumping of the Mulberry Well enhances the existing downward vertical gradient and is expected to provide containment of the deep plume in the Mulberry Well Production Zone, which is directed towards the Mulberry Well under pumping conditions. Pumping is expected to prevent migration of contaminant mass deeper than the Mulberry Well production zone. The Mulberry Well production zone essentially functions as a blanket drain beneath low hydraulic conductivity strata which contains majority of the TCE plume.

It is recommended that additional numerical modeling be conducted during the Remedial Design phase to optimize pumping rates for Remedial Action implementation.

Pending MDNR approval of this supplemental RI Report, a FS Report will be developed which discusses potential options for implementation and operation of pumping systems for the Mulberry Well.
5.0 CLOSING

Golder appreciates the opportunity to assist the City of Camdenton with this project. Please feel free to contact Rick Booth with questions or comments at (314) 971-2711 or rbooth@golder.com.

Sincerely,

GOLDER ASSOCIATES INC.

Justin C. White, P.E.
Senior Project Geological Engineer

Frederick M. Booth, R.G.
Principal and Program Leader

JCW/AMF/FMB
6.0 REFERENCES


TABLES
## Table 2
Pre-Design Groundwater Analytical Detections
Supplemental RI Report/Addendum
Former Hulett Lagoon Site
Camdenton, MO

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>Analyte</th>
<th>Volatile Organic Compounds (VOCs)</th>
<th>Units US EPA MCL</th>
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<tr>
<td></td>
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<td>UNITS US EPA MCL</td>
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Notes:
- Bold - Indicates a detection
- ft bgs - Feet below ground surface
- J - Analyte detected below quantitation limit
- µg/L - micrograms per liter
- MDNR - Missouri Department of Natural Resources
- NIA - not applicable
- NPDES - National Pollutant Discharge Elimination System
- psi - pounds per square inch
- US EPA - United States Environmental Protection Agency
- MCL - Maximum Contaminant Level

Monthly and daily trichloroethene limits based on site-specific MDNR NPDES permit number MO-0124389. Monthly number listed in the average.


Purple highlight denotes exceedance of MDNR NPDES permit daily maximum threshold.

Orange highlight denotes exceedance of US EPA MCL.

Drawdown value listed is the maximum value measured during the September 2016 pumping test.

Prepared by: EPW 10/06/2016, JS 3/31/2017
Checked by: GS 10/07/2016
Reviewed by: AMF 7/10/2017
### Table 3
Pumping Test Groundwater Analytical Detections
Supplemental RI Report/Addendum
Former Hulett Lagoon Site
Camdenton, MO

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<thead>
<tr>
<th>Sample Date</th>
<th>UNITS</th>
<th>MDNR Site-Specific NPDES Guidelines</th>
<th>US EPA MCL</th>
<th>MWPT-1</th>
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<td>cis-1,2-Dichloroethene</td>
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<td>Hardness (as CaCO₃)</td>
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<td>1.00 U</td>
<td>0.510 J</td>
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</tbody>
</table>

Notes:
- Bold - Indicates a detection
- J - Analyte detected below quantitation limit
- U - Analyte detected above the method detection limit (MDL), value shown is the reporting limit
- µg/L - micrograms per liter
- mg/L - milligrams per liter
- N/A - not applicable
- NL - not listed

MDNR - Missouri Department of Natural Resources
NPDES - National Pollutant Discharge Elimination System
US EPA - United States Environmental Protection Agency
MCL - Maximum Contaminant Level

Monthly and daily trichloroethene limits based on site-specific MDNR NPDES permit number MO-0124389. Monthly number listed in the average.

US EPA MCL taken from the EPA Regional Screening Levels (RSLs) - Generic Tables (May 2016) accessed at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016.
Orange highlight denotes exceedance of US EPA MCL.

Checked by: KK 11/08/2016
Reviewed by: AMF/FMB 11/27/16