Appendix Q

Description of Modeling and Groundwater Recovery/Disposal Calculations and Cost Estimates for Active Remediation of Guidry Limited Admission Groundwater Area

As previously noted in other proceedings with the Louisiana Department of Natural Resources (LDNR), submitting parties have been asked to provide and consider remedial options addressed to restoration of background conditions for groundwater, and that potential is addressed in anticipation of that request. Based on laboratory analytical results, elevated chloride and barium parameters[1] exist in the vicinity of ICON monitor wells GC8 and GC12 and HET monitor wells MW5 and MW7. Accelerated removal or reduction of these constituents would require active groundwater withdrawal. As noted below, any proposal for such a plan would require further feasibility study and analysis, and actual design and cost of such a system at this stage is inherently speculative. Although it remains premature, in order to address the requirement for discussion of an option, a plan contemplating active groundwater remediation has been prepared. The remedial objective for purposes of this discussion is compliance with applicable EPA Secondary Drinking Water standards, which are considered to be within the range of background conditions surrounding the Limited Admission groundwater area. This plan is not endorsed by the authors because it is not the most feasible option and because design and selection of such an option is premature; however, a pump and treat option is proposed in anticipation of regulatory requests and for evaluation as a possible contingency plan for remediation in the Limited Admission area.

The considered pump and treat plan includes two (2) recovery wells (RW-1 and RW-2) installed within the intermediate zone (Figure 26) and a local injection well to dispose of recovered water. The placement and function of these wells were assessed in coordination with B. Kueper & Associates, Ltd., who performed certain modeling and other calculations based on existing data for the Limited Admission zone and groundwater zones adjacent to it, which are provided below. The cost of implementing such a plan, including installation of a local injection well for disposal of recovered water, is calculated to be $2,999,863.37.

[1] Radium levels were found exceeding the EPA drinking water standards, but were within levels of naturally occurring radium for this site.

Modeling to Estimate Remedial Option

A numerical groundwater flow model was developed to estimate the number of recovery wells, flow rates and duration of pumping within the Limited Admission zone. The numerical model utilized the United States Geologic Survey (USGS) software packages MODFLOW-2005 and MODPATH. MODFLOW-2005 is a finite difference model that can simulate three-dimensional groundwater flow in a heterogeneous aquifer comprising porous media. The domain can have an irregular shape, an irregular grid and various boundary conditions, including multiple recovery wells pumping at variable flow rates. Flow can be either steady-state or transient. MODPATH is a forward and backward particle tracking algorithm that facilitates the visualization of groundwater flow direction and capture zone extents. The model was constructed with the pre- and post-processor software package Groundwater Vistas Version 6 (GV6) by Environmental Simulations Incorporated.

The model domain had a plan view footprint of 10,000 feet by 10,000 feet. The model origin (bottom left hand corner) was located at an easting of 308243.7 feet and northing of 631929.1 feet (State Plane Louisiana South) with a grid rotation of 38.6 degrees counter clockwise. The property was located at the center of the model. The domain vertically extended from ground surface (approximately twenty (20) feet NGVD) to -480 feet elevation. The model grid was discretized into 181 rows, 237 columns and 143 layers. The horizontal grid spacing was variable with 100 foot by 100 foot grid cells at the domain edges refined to twenty (20) feet by twenty (20) feet on the Guidry property. The vertical grid spacing was variable. The top model layer was created with the LiDAR digital elevation model (DEM) distributed by the Louisiana State University CADGIS Research Laboratory. Irregular model layers were created from ground surface to zero (0) foot elevation. From zero (0) foot elevation to -480 foot elevation planar layers were utilized. For the interval of approximately -10 foot elevation to -60 foot elevation the layer thickness was variable with a minimum thickness of approximately 1 ft.

The model hydraulic conductivity values were adopted from various sources. From ground surface to thirty (30) feet bgs is predominantly silty/clayey soil. HET collected seven (7) soil samples from twenty-two (22) feet to twenty-six (26) feet bgs (within silty/clayey unit) for geotechnical analysis of vertical hydraulic conductivity (K_v). The resulting geometric mean K_v was 1.98E-8 cm/s (5.6E-5 feet/d), which was adopted in the model for all clayey units. A 10:1 anisotropy for horizontal (K_H) to vertical hydraulic conductivity was utilized for all soil types. A K_H value of 2.85 feet/d was adopted from the 2017 ICON Export Report for the shallow zone. The K_H values for the intermediate and deep zones were adopted from the HET slug test results, which were 92.7 feet/d and 164.7 feet/d, respectively. Within the model, the shallow zone extended from thirty (30) feet bgs to -25 feet elevation, the intermediate zone extended from -25 foot to -60 foot elevation, and the deep zone was below -60 foot elevation. Based on a review of borehole lithology, discontinuous clay lenses were added to the intermediate zone at the northwest portion of the property. In addition, a continuous model-wide clay layer from -130 foot to -140 foot elevation was implemented.

Constant head boundary (CHB) conditions were applied to the upgradient and downgradient faces of the model to recreate flow from the northeast toward the southwest. A horizontal component of hydraulic gradient of 0.0003 was assumed based on multiple estimates from the monitoring well network. The vertical component of hydraulic gradient was assumed to be negligible. Due to the variability in hydraulic head measurements across the Guidry site, the magnitude of the CHBs was assigned such that a modelled hydraulic head of one (1) foot was achieved at the center of the property. Utilizing the LiDAR DEM, a portion of the eastern wetland area was assigned a constant stage boundary condition using the river package.

All LDNR registered water wells and unregistered water wells sampled for groundwater chloride during Guidry field investigation were added to the model as continuous pumping wells. Known well screen intervals were implemented in the model. If the well screen was unknown, a screen length of ten (10) feet terminating at the known bottom depth of the well was assumed. A steady-state extraction rate of 800 gpd was adopted for all water wells.

The EPA Batch Flushing Model (BFM) equation was utilized to approximate the number of extracted pore volumes (*NPV*) of groundwater needed to reduce current chloride concentrations within the 1,000 mg/L chloride concentration contour in the Limited Admission zone to a target concentration. The BFM equation is given by $NPV = -R_f ln\left(\frac{C_f}{C_o}\right)$, where R_f is the retardation factor (1.0 for chloride), C_f is the final concentration and C_o is the initial concentration. The BFM is a simplified expression that does not incorporate fundamental processes, such as advection and dispersion. However, it has been observed that the BFM often yields relatively good agreement with results from actual groundwater recovery systems. The BFM is generally considered a scoping-level approximation. Within the 1,000 mg/L chloride contour, the C_o was 4,360 mg/L (approximate arithmetic mean chloride concentration from HET MW-7, ICON GC-8D and ICON GC-12D) and the C_f was 250 mg/L. The resulting NPV was 2.9.

The numerical model was utilized to iteratively estimate the preliminary configuration of the recovery wells for the limited admission zone. Using GV6, recovery wells were added to the model as analytic elements and backwards tracking particles were released from the recovery well screens to visually observe capture. All simulations were executed with steady-state conditions. The resulting configuration comprises two (2) recovery wells screened from -30 feet to -55 feet elevation with individual flow rates of 36.4 gpm (72.8 gpm total) operating continuously for one (1) year. The total volume of extracted groundwater was approximately 3.8E-7 gallons, which equates to approximately 3.3 pore volumes. The locations of the two (2) extraction wells are depicted on Figure 26.

Disposal of Recovered Water

A key element of the feasibility of a pump and treat contingency plan is the method of handling and disposal of recovered groundwater. The elements of groundwater recovered from the Limited Admission zone are remnants of produced water or other non-hazardous oilfield waste (NOW) and upon recovery will contain a small fraction of their initial concentrations. Recovered groundwater will be pumped to tanks and systems designed by Don Bazer in consultation with HET as reflected in Attachment Q-1. The water will then be injected for local disposal by underground injection in a well to be completed in accordance with the design provided by Mr. Bazer, provided in Attachment Q-2. If necessary, BP will place the well on property it owns immediately adjacent to the Limited Admission groundwater area.

Cost Estimating

HET, in consultation with Don Bazer, has estimated the cost of establishing and operating the groundwater recovery and disposal system described above. The precise timing, function, and operation of such a system to achieve remedial goals will require completion of additional field evaluation as proposed. Based on calculations performed by B. Kueper & Associates, Ltd., however, a current estimate for installation and operation of this system over a period of one (1) year yields a total cost of $2,999,863.37. An itemized list of costs is attached.