Memorandum

DATE: September 13, 2024

TO: John Mefford, Department of Ecology

FROM: Kyle Johnson, LG / Tom Mergy, LHG

PROJECT: Coleman Oil Yakima Bulk Plant Site
Ecology Agreed Order No. DE 23182
PBS No. 41392.000, Phase 0021, Task 03A

REGARDING: Preliminary Results of the Surfactant Pilot Test – August 2024

This memo presents the detailed findings from the surfactant pilot test conducted at the site. The objective of the test was to evaluate the effectiveness of surfactant injection and subsequent extraction in mobilizing and recovering Light Non-Aqueous Phase Liquid (LNAPL). The pilot scope was presented in the Pilot Test Work Plan (PBS - approved August 2024). The pilot test included the injection by gravity feed of 250 gallons for the surfactant mixture into the RW-1 well, and subsequent extraction of water and surfactant from Recovery Well, RW-1 after an approximate 40-hour period. The extracted water was pumped using a submersible pneumatic pump with water containerized in three 250-gallon totes located at the facility.

Observations of the surfactant pump test were made at six monitoring wells, with data categorized into phases: Before Injection, During Injection, During Residency Time (between injection and extraction), During Extraction, and After Extraction.

RW-1

RW-1 was the well used for both surfactant injection and extraction. Monitoring at RW-1 included continuous measurements of groundwater levels using a pressure transducer datalogger, LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **Before Injection:**
  Groundwater elevation at RW-1 was recorded at 1070.04 feet, establishing the baseline for evaluating changes during the surfactant injection and extraction phases.
- **During Injection (11:48 to 12:48 on 8/20):**
  Groundwater elevation rose sharply to 1073.62 feet, a total increase of 3.58 feet (approximately 0.06 feet per minute) in response to the injection of surfactant at a rate of 4.4 gallons per minute. This rise reflects the immediate hydraulic response to the volume of surfactant introduced.
- **During Residency Time:**
  Following injection, groundwater levels began to gradually recede, reaching 1070.67 feet within approximately nine hours. This 2.95-foot decrease from the peak elevation reflects the dispersal of the surfactant through the aquifer.

- **During Extraction (09:00 to 15:28 on 8/22):**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **1 GPM:** 1070.00 feet (0.67-foot decrease from before injection)
  - **2 GPM:** 1069.60 feet (0.40-foot decrease)
  - **3 GPM:** 1069.20 feet (0.40-foot decrease)
  - **3.25 GPM:** 1069.00 feet (0.20-foot decrease)
- **After Extraction:**
  Groundwater levels rebounded rapidly, rising to 1070.00 feet within 30 minutes after extraction pumping ceased. This 1.0-foot increase indicates a relatively fast aquifer recovery, driven by natural capacity of the aquifer in proximity of RW-1.

LNAPL Thickness

- **Before Injection:**
  LNAPL thickness was minimal at 0.01 feet.
- **During Injection:**
  No LNAPL was detected during injection due to the rise in groundwater levels.
- **During Residency Time:**
  LNAPL began to reappear within 1 hour and 40 minutes after injection, with a thickness of 0.01 feet. Thickness fluctuated between 0.01 and 0.02 feet and reached 0.03 feet just before extraction began.
- **During Extraction:**
  LNAPL thickness could not be measured due to the pump within the well.
- **After Extraction:**
  Seventeen minutes after extraction ceased, LNAPL thickness was measured at 0.23 feet, confirming that the surfactant and extraction mobilized the LNAPL toward the extraction well.

Surfactant Levels

Surfactant levels are reported as observations from the Ivey-Sol field screening tests, scaled from 0 (no surfactant) to 4 (saturated surfactant).

- **Before Injection:**
  No surfactant was observed at RW-1 prior to injection.
- **During Injection:**
  Surfactant levels reached a saturation level of 4 within 12 minutes of injection and remained at this level throughout the injection.
- **During Residency Time:**
  Surfactant levels began to decline approximately 2 hours and 20 minutes after injection, decreasing to 3. By the time extraction began (44 hours post-injection), surfactant levels had further reduced to 2, indicating surfactant was being dispersed into the aquifer.
- **During Extraction:**
  Surfactant levels during extraction were observed as follows:
  - 1 hour 57 minutes into extraction: **Level 3**

- 4 hours 8 minutes into extraction: **Level 2**
- 4 hours 55 minutes into extraction: **Level 1**
- 6 hours 28 minutes into extraction: **Level 0**

These results indicate that surfactant was effectively recovered during extraction.

MW-1

MW-1 is located approximately 15 feet upgradient of RW-1. Monitoring at MW-1 included continuous measurements of groundwater levels using a pressure transducer datalogger, LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **Before Injection:**
  Groundwater elevation at MW-1 was 1071.14 feet.
- **During Injection:**
  Groundwater levels increased 0.47 feet to 1071.61 feet, indicating a slight hydraulic influence from the surfactant injection.
- **During Residency Time:**
  Groundwater levels gradually receded to 1071.14 feet within nine hours. Prior to extraction, the level had slightly risen to 1071.21 feet.
- **During Extraction:**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **1 GPM:** 1071.17 feet (0.03 feet above baseline)
  - **2 GPM:** 1071.07 feet (0.07 feet below baseline)
  - **3 GPM:** 1070.92 feet (0.22 feet below baseline)
  - **3.25 GPM:** 1070.78 feet (0.36 feet below baseline)
- **After Extraction:**
  The groundwater level rebounded to 1070.84 feet within 20 minutes of extraction pumping end.

LNAPL Thickness

- **Before Injection:**
  LNAPL thickness was measured at 0.01 feet.
- **During Injection:**
  No LNAPL was detected due to rising groundwater levels.
- **During Residency Time:**
  LNAPL thickness fluctuated between 0.01 and 0.02 feet. LNAPL was absent just before extraction began.
- **During Extraction:**
  LNAPL reached a maximum thickness of 0.06 feet after 3 hours and 42 minutes of pumping, with 0.02 feet measured just before the end of extraction.

Surfactant Levels

Surfactant levels are reported as observations from field tests, scaled from 0 (no surfactant) to 4 (saturated surfactant).

- **During Injection:**
  Surfactant reached MW-1 within 2 hours and 20 minutes after injection, reaching a saturation level of 4.
- **During Residency Time:**
  Surfactant levels fluctuated between 0 and 3 and settled to 2 before extraction.
- **During Extraction:**
  Surfactant levels remained at 1 throughout extraction. Within six hours and twenty-three minutes, surfactant levels returned to baseline.

MW-2

MW-2 is located 27 feet cross-gradient from RW-1. Monitoring at MW-2 included groundwater levels and LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **Before Injection:**
  The baseline groundwater elevation at MW-2 was recorded at 1071.24 feet.
- **During Residency Time:**
  Following injection, the groundwater level at MW-2 remained relatively stable and fluctuated minimally around the baseline.
- **During Extraction:**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **3 GPM:** 1070.74 feet (0.50 feet below baseline)
  - **3.25 GPM (after 49 minutes):** 1070.88 feet (0.36 feet below baseline)
  - **3.25 GPM (after 2 hours and 50 minutes):** 1070.94 feet (0.3 feet below baseline)

  These fluctuations indicate that MW-2 was moderately affected by hydraulic changes during extraction, with some groundwater recovery occurring as pumping continued.

LNAPL Thickness

- **Before Injection:**
  No measurable LNAPL was detected in MW-2.
- **During Extraction:**
  Approximately five hours and 50 minutes into extraction, LNAPL was measured at 0.01 feet.

Surfactant Levels

Surfactant levels are reported as observations from field tests, scaled from 0 (no surfactant) to 4 (saturated surfactant).

- **During Injection:**
  Surfactant was detected in MW-2 two hours and 40 minutes after injection started, with levels rising to 1.
- **During Residency Time:**
  Surfactant levels fluctuated between 0 and 1 during the residency period.
- **During Extraction:**
  Surfactant levels remained at 1 throughout the extraction phase. Surfactant presence returned to baseline levels after five hours and 50 minutes.

MW-3

MW-3 is located 20.5 feet downgradient from RW-1. Monitoring at MW-3 included continuous measurements of groundwater levels using a pressure transducer datalogger, LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **Before Injection:**
  The baseline groundwater elevation at MW-3 was 1069.97 feet.
- **During Injection:**
  Groundwater levels increased to 1069.94 feet during injection, indicating that the hydraulic pressure from surfactant injection extended downgradient to MW-3.
- **During Residency Time:**
  Groundwater levels gradually decreased following injection but stabilized at 1069.72 feet within nine hours, suggesting that the hydraulic effects of the surfactant injection persisted during the residency time as the mixture continued to disperse through the formation.
- **During Extraction:**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **1 GPM:** 1069.88 feet (0.09 feet below baseline)
  - **2 GPM:** 1069.72 feet (0.25 feet below baseline)
  - **3 GPM:** 1069.46 feet (0.51 feet below baseline)
  - **3.25 GPM:** 1069.17 feet (0.80 feet below baseline)

  These observations demonstrate a significant drawdown in the downgradient direction.

- **After Extraction:**
  After pumping ceased, groundwater levels rebounded to 1069.40 feet within 25 minutes.

LNAPL Thickness

- **Before Injection:**
  Before surfactant injection, LNAPL thickness at MW-3 was recorded at 1.10 feet.

- **During Injection:**
  LNAPL thickness decreased sharply to 0.35 feet by approximately 20 minutes after injection concluded. This decrease suggests that the rising groundwater levels during injection caused some displacement of LNAPL.
- **During Residency Time:**
  During the residency period, LNAPL thickness fluctuated and reached a maximum of 0.47 feet two hours and 58 minutes after injection. By the time extraction started, LNAPL thickness had reduced to 0.02 feet.
- **During Extraction:**
  LNAPL thickness reached 0.11 feet after two hours and 14 minutes of pumping. However, thickness fluctuated throughout the extraction period, eventually measuring 0.08 feet just before extraction ended. This suggests that some product was mobilized toward RW-1.

Surfactant Levels

Surfactant levels are reported as observations from field tests, scaled from 0 (no surfactant) to 4 (saturated surfactant).

- **During Injection:**
  Surfactant was detected at MW-3 within 53 minutes into injection, reaching a saturation level of 4.
- **During Residency Time:**
  Surfactant levels gradually decreased, reaching a level of 3 one hour and 17 minutes after injection finished. By the time extraction began (44 hours after injection), surfactant levels had decreased further to 2.
- **During Extraction:**
  Surfactant levels during extraction began at level 2 and dropped to level 1 after four hours and 50 minutes. Surfactant returned to baseline levels approximately six hours into the extraction phase.

MW-12

MW-12 is located 95 feet downgradient from RW-1. Monitoring at MW-12 included groundwater levels and LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **During Injection:**
  Halfway through the injection phase, the groundwater elevation at MW-12 was recorded at 1067.54 feet.
- **During Residency Time:**
  Two hours and 49 minutes after injection, groundwater elevation was measured at 1067.46 feet, fluctuating between 1067.37 and 1067.46 feet over the following day. These minor fluctuations suggest that MW-12 was moderately impacted by the surfactant injection.
- **During Extraction:**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **1 GPM (after 15 minutes):** 1067.69 feet (0.15 feet above baseline)

- **2 GPM (after 40 minutes):** 1067.14 feet (0.40 feet below baseline)
- **3 GPM (after 30 minutes):** 1067.59 feet (0.05 feet above baseline)
- **3.25 GPM (just before extraction ended):** 1067.66 feet (0.12 feet above baseline)

These fluctuations indicate moderate zone of influence as extraction progressed.

LNAPL Thickness

- **During Injection:**
  Midway through injection, LNAPL thickness was measured at 1.37 feet at MW-12.
- **During Residency Time:**
  LNAPL thickness fluctuated between 1.37- and 1.42-feet during residency time.
- **During Extraction:**
  LNAPL thickness peaked at 1.62 feet approximately one hour and 20 minutes into extraction but fluctuated throughout the remainder of the extraction period. By the time extraction concluded, LNAPL thickness had decreased to 0.98 feet. This indicates moderate movement of LNALP from MW-12.

Surfactant Levels

- **During Residency Time:**
  Surfactant was detected in MW-12 during the first field test, conducted 30 minutes after injection ended, with levels measured at 1. The surfactant concentration gradually increased to level 2 approximately two hours and 52 minutes post-injection.
- **During Extraction:**
  Surfactant levels in MW-12 remained stable at 1 throughout the extraction period, returning to baseline levels soon after extraction ended.

MW-13

MW-13 is located approximately 145 feet downgradient from RW-1. Monitoring at MW-13 included groundwater levels and LNAPL thickness using an interface probe, and surfactant concentration using Ivey-Sol field tests.

Groundwater Levels

- **During Residency Time:**
  The first groundwater elevation measurement at MW-13 occurred four hours and 20 minutes after injection was completed, with the level recorded at 1069.04 feet. Over the following 24 hours, groundwater levels fluctuated slightly, ranging between 1069.02 and 1069.04 feet.
- **During Extraction:**
  Extraction was conducted at varying flow rates. Groundwater levels stabilized as follows:
  - **1 GPM (after 20 minutes):** 1069.05 feet (0.01 feet above baseline)
  - **2 GPM (after 50 minutes):** 1069.00 feet (0.04 feet below baseline)
  - **3 GPM (after 74 minutes):** 1068.99 feet (0.05 feet below baseline)
  - **3.25 GPM (2 minutes after extraction ended):** 1068.97 feet (0.07 feet below baseline)

These small changes demonstrate that minor hydraulic drawdown effects extended to MW-13.

LNAPL Thickness

- **During Residency Time:**
  LNAPL thickness was measured at 0.01 feet in MW-13 four hours and 20 minutes after injection. The thickness fluctuated slightly between 0.02 and 0.03 feet over the following day.
- **During Extraction:**
  Throughout the extraction period, LNAPL thickness remained consistent at 0.01 feet. This suggests that extraction at RW-1 had a negligible impact on mobilizing product this far downgradient.

Surfactant Levels

Surfactant levels are reported as observations from field tests, scaled from 0 (no surfactant) to 4 (saturated surfactant).

- **During Residency Time:**
  Surfactant levels in MW-13 were measured at 1 during the first field test, which was conducted 40 minutes after injection concluded. Surfactant levels increased slightly to 2 by approximately 26 hours after injection.
- **During Extraction:**
  Surfactant levels remained at 1 throughout the extraction phase, with surfactant returning to baseline soon after extraction concluded. This suggests that surfactant concentrations were effectively removed during the pumping phase.

RADIUS OF INFLUENCE

Note that the following interpretations are based on when changes were observed or measured, and the exact timing is unknown. The exceptions are groundwater elevation in RW-1, MW-1, and MW-3, which was measured continuously by dataloggers at a 1-minute frequency throughout the test.

Surfactant Injection Radius of Influence

Based on data collected from all six wells, the radius of influence (ROI) for surfactant injection can be estimated in all directions from RW-1. Given the varied timing of surfactant detection across wells, the rates of movement differ significantly depending on distance and gradient direction.

- **Upgradient (MW-1, ~15 feet from RW-1):**
  Surfactant reached MW-1 within two hours and 20 minutes after injection began, indicating a movement rate of more than 6.4 feet per hour. The upgradient ROI is estimated to extend up to 25 feet.
- **Cross-Gradient (MW-2, ~27 feet from RW-1):**
  Surfactant was detected at MW-2 within two hours and 40 minutes, indicating a movement rate of more than 10.1 feet per hour. The cross-gradient ROI likely extends between 35 and 40 feet.
- **Downgradient (MW-3, MW-12, MW-13):**
  - Surfactant reached MW-3 (~20.5 feet downgradient) within one hour and 17 minutes, indicating a movement rate of more than 16 feet per hour.

- Surfactant reached MW-12 (~95 feet downgradient) within two hours and 49 minutes, indicating a movement rate of more than 33.8 feet per hour.

Based on these observations, the estimated downgradient ROI extends up to 150 feet or more, with the movement rate slowing as the distance increases.

Pumping Radius of Influence

The radius of influence for groundwater drawdown during extraction varied depending on the gradient direction:

- **Upgradient (MW-1):**
  Minimal drawdown was observed at MW-1, and recovery occurred rapidly after pumping stopped. The upgradient drawdown ROI is estimated to extend 20-25 feet.
- **Cross-Gradient (MW-2):**
  Moderate drawdown was observed, with the cross-gradient drawdown ROI extending approximately 30-35 feet. Groundwater recovery was gradual throughout the extraction phase.
- **Downgradient (MW-3, MW-12, MW-13):**
  - Drawdown effects were nearly immediate at MW-3.
  - At MW-12 (~95 feet), drawdown effects became apparent within 30-40 minutes of pumping, indicating a rate of more than 2-3 feet per minute.
  - MW-13 (~145 feet) experienced minimal drawdown, detected within 20-50 minutes of pumping.

  The downgradient drawdown ROI is estimated to extend up to 120 feet, with significant groundwater level effects detected as far as MW-12.

LNAPL Mobilization Radius of Influence

- **Upgradient (MW-1):**
  LNAPL transport was minimal in the upgradient direction, with little product thickness change detected. The transport ROI is estimated to extend 15-25 feet upgradient.
- **Cross-Gradient (MW-2):**
  LNAPL transport was also minimal in the cross-gradient direction, with little to no product detected. The estimated transport ROI extends 20-25 feet.
- **Downgradient (MW-3, MW-12):**
  LNAPL transport occurred more quickly downgradient, reaching MW-3 (~20.5 feet) at a rate of more than 15-16 feet per hour. At MW-12, LNAPL transport occurred at rates of more than 47.5 feet per hour. The estimated downgradient transport ROI extends up to 100 feet.

CONCLUSIONS

The surfactant injection and extraction pilot test provided valuable insights into the effectiveness of mobilizing and recovering LNAPL at this site. Based on observations across the six wells, we can draw the following conclusions:

1. **Surfactant Propagation**: Surfactant injected at a rate of 4.4 gal/min influenced subsurface conditions in all directions from RW-1, with the greatest impact observed downgradient due to natural groundwater flow. Surfactant migrated at rates of over 6.4 feet per hour upgradient, 10.1 feet per hour cross-gradient, and 33.8 feet per hour downgradient, reaching distances of up or exceeding 150 feet.

2. **Pumping Radius of Influence**: Groundwater extraction caused drawdown effects up to 120 feet downgradient, with slower and more limited effects observed cross-gradient (30-35 feet) and upgradient (20-25 feet).
3. **LNAPL Mobilization**: The test effectively mobilized LNAPL, particularly in the downgradient direction.
4. **Surfactant Removal**: Surfactant concentrations in all wells returned to baseline by the end of extraction, confirming that surfactant was effectively mobilized and removed during extraction.

The pilot test confirmed the feasibility of surfactant injection and extraction as an effective means of mobilizing and recovering LNAPL from the subsurface. The data collected provides a robust foundation for designing and implementing a full-scale remediation system tailored to the site's hydrogeologic conditions.

Reviewer: TM